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MEDDELANDEN FRÅN SKOGSFORSKNINGSINSTITUTET I FINLAND
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A METHOD OF COMBINING PHOTO AND FIELD SAMPLES IN FOREST INVENTORY

Ilmakuva- ja maasto-otokseen perustuva
metsän inventointimenetelmä

Simo Poso

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PREFACE

The present study originated as part of a larger project dealing with the use of aerial photographs in forest inventory and mapping. The project was planned in the Finnish Forest Research Institute and at the University of Helsinki in the departments dealing with forest mensuration, management and inventory. Professors KULLERVO KUUSELA and AARNE NYYSSÖNEN acted as supervisors of the project. I am deeply indebted to them for the facilities they have made available and the fine atmosphere I have experienced during the course of my research. They also offered helpful advice in planning and completing the study.

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Helsinki, May, 1972

Simo Poso

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1. INTRODUCTION

11. Various types of forest-inventory methods

The concept *forest-inventory method* has been applied in this paper to include all the phases necessary to produce the data required for management or decision-making purposes. Accordingly, in defining a method one should describe such phases as sampling design and procedures for calculating the results with certain confidence levels. The definition or derivation of the most suitable method for a given situation should be considered in the light of factors such as goal-setting, the forestry entrepreneur, the extent of the forest area, the importance of forestry, occupational standards, technical aids available, etc.

Forest-inventory methods can be classified according to their objectives as (cf. FAO 1968, pp. V-2): (1) national forest inventories, (2) working-plan surveys, (3) reconnaissance forest surveys, (4) logging-plan surveys, (5) basic information compilation for forest industry and feasibility studies, and (6) basic data determination for stumpage appraisal. JOHNSTON, GRAYSON & BRADLEY (1967, p. 466) list three main categories under which most forest inventories can be classified: (1) national or state inventories covering several types of ownership, (2) inventories which cover all forests within a single ownership, and (3) inventories of individual management units.

Finnish forest inventories to date have used methods almost exclusively based on field work. On small Finnish forest lots, no special inventory methods are used. Management and decisions are mainly based on memorized knowledge of earlier actions and on an assessment of the present situation supplemented by checks subjectively made in the field. This substitution for a special inventory causes difficulties in comparing alternatives and may easily lead to neglected silviculture and mistaken conclusions. The value of the procedure, however, depends primarily on how well its user knows his job.

The inventory method recommended for forest lots of more than about 50 ha is based on ocular estimates of forests in compartments. A forest map is necessary for location and area estimations. Usually the borderlines of the compartments are first drawn on aerial photographs by photo interpretation. Uncertain borderlines are checked in the field and incorrect lengths corrected in connection with the ocular estimation of the compartments in the field.

Estimation of stand characteristics is seldom based on photo interpretation. The photographs can be used to plan the route through the forest and to select the most representative places of the stand compartments for field estimations. Usually every stand compartment must be visited.

The national forest inventories, and some extensive inventories within a single ownership (e.g. forest-industry companies), are carried out in Finland on the basis of sampling, almost always on plots systematically located either by strips or tracts. Examples are the five national forest inventories of Finland since the early 1920s (e.g. ILVESSALO 1927; KUUSELA & SALMINEN 1969). The statistical mathematics underlying these methods have been studied in particular by LINDEBERG (1924, 1926). Comparable studies in Scandinavia have been made by LANGSAETER (1926), NÄSLUND (1930) and MATÉRN (1947, 1960).

As the forests are continuously changing, primarily through growth and cuttings, it is necessary periodically to repeat the inventory. The forest inventories should thus be regarded as a continuous system. When choosing or developing the inventory method, the whole system rather than only one inventory task should be taken into consideration. The end result may be to suggest using a method called *sampling with partial replacement* (cf. BICKFORD, MAYER & WARE 1963, p. 828). The statistical mathematics applicable to forest inventories have been described by WARE & CUNIA (1962), among others. In Finland, this method has been studied and applied by NYYSSÖNEN (1967), and, for the determination of timber removal, by SEPPÄLÄ (1971).

The methods by which a large number of plots are interpreted from aerial photographs and a smaller number of these sub-sampled in the field are termed in statistics as methods based on double sampling. They have been widely used for forest inventories in the USA and Canada (HILDEBRANDT 1961, 1962). Empirical studies for applying these methods in Finland have been carried out by NYYSSÖNEN, POSO & KEIL (1968).

12. Conditions for the application of methods involving photo interpretation

121. General survey

Inventory methods should be viewed in time perspective. A method that once was considered to be best may become obsolete as the external conditions change. In time perspective, it would often be more correct to think of updating than improving the methods of inventory. If the factors (payroll, technical

progress, application of results) affecting the choice of inventory method undergo rapid changes, this tends to call for modifications in the method applied or selection of a completely different method. Against the background of external changes, the method should be made as flexible as possible vis-à-vis technical amendments.

The developments which started with the Industrial Revolution of the early 18th century in Great Britain are leading to increasing substitution of human manual labour by machine power. An example of the rapid change today is the mechanization of forest work in Finland. The incentives for the elimination of human manual labour include the rapid technical development of machines and the increase in the cost of human labour at a faster pace than the cost of mechanized work.

Mechanization has made slow progress in the field work required for forest inventories. Measuring instruments have changed relatively little. The most important change is perhaps the improvement of traffic conditions (roads, motor vehicles), which has made it easier to reach the objects to be measured. This notwithstanding, the cost of field work per sample plot has steadily increased, for example in the Finnish national forest inventories, as a result of general wage rises and other changes required in working conditions.

Under the double-sampling methods using aerial photographs, both field work and the photographs cause costs. Costs for aerial photos are incurred in obtaining the photos and interpreting the plots on them. These costs may be expected to rise more slowly in the near future than the costs for field work.

The changes in cost relations, produced by changed conditions, tend to improve the relative profitability of the methods based on aerial photos compared with those based on field work alone. A similar effect is also produced if correlation of photo interpretation and field measurements can be improved (better standards of aerial photographs and interpretation methods, a higher level of training, etc.), and if the methods of applying the double-sampling technique can be developed.

Another factor of considerable influence on the relative profitability of various methods is related to changes which may take place in the objectives of the inventory. If, for example, extensive inventories must produce data on volumes in relatively small regions, this may necessarily lead to the use of aerial photographs. On the other hand, such inventory objectives as classification of forest land according to silvicultural condition at a certain confidence level may suggest pure field sampling.

A drawback inherent in the application of double-sampling technique is that the resulting method requires more calculation work and expertise than that based on field sampling alone. On the other hand, this drawback loses some of its importance with the increasingly common use of computers.

122. Technical state of aerial photos

The technique of aerial photography and photo interpretation was stimulated in particular by World War II. Progress has been prompted mostly by the desire to improve reconnaissance methods for military and space-research purposes. The present trend is toward increasing use of invisible wave-lengths of electromagnetic radiation (e.g. thermal and radar photography). In the following, however, attention will only be given to a photographic area (wave-lengths of 0.35—1.3 micrometres) which, in addition to visible wave-lengths, includes some ultraviolet and infra-red wave-length bands.

Many factors affect the interpretability of the photos. Within certain limits, some of these factors can be technically controlled, such as the camera carrier (aircraft), camera, film and film-development equipment. Another range of factors, including for example weather conditions, often produces unforeseeable variations in the quality of the protographs.

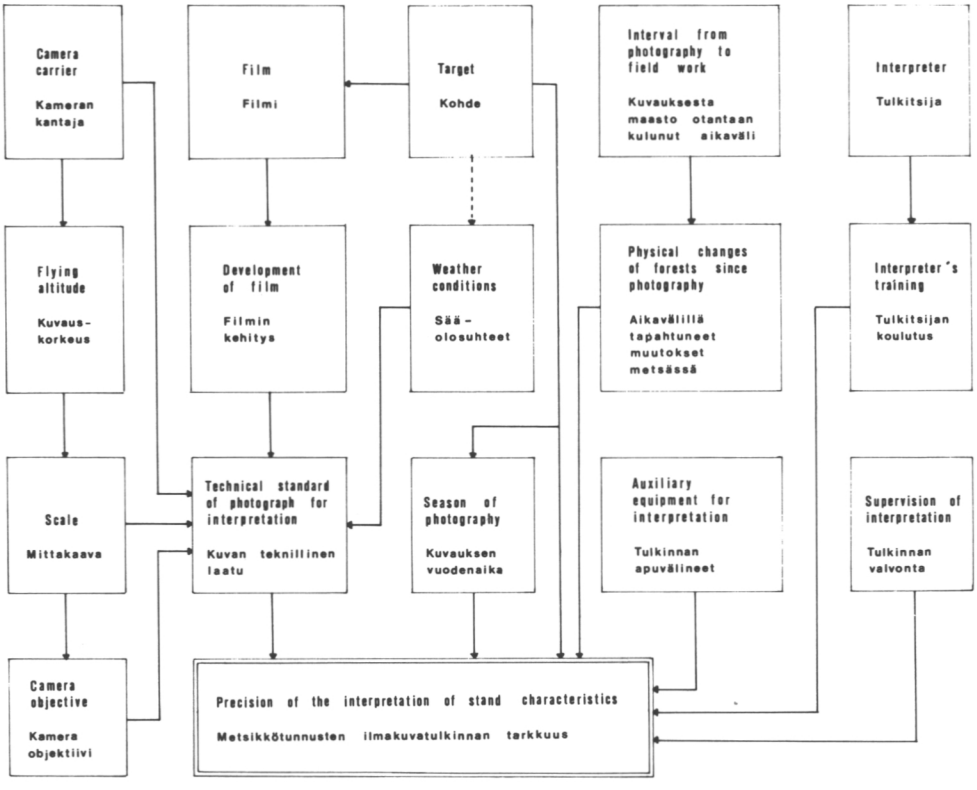


Fig. 122.1. Factors affecting the precision of photo interpretation
Kuva 122.1. Ilmakuvatulkinnan tarkkuuteen vaikuttavia tekijöitä

The resolving power of the best, generally-used cameras (Zeiss, Wild) today is about 60 line pairs per mm. Special cameras (HyAc panorama and Sonne strip-photography cameras) have a resolving power often exceeding 200 line pairs per mm (LAUER 1967). (A line pair consists of two lines of equal width but different contrast, e.g. a white and a black line side by side form a line pair.) A film resolving power of 30—70 line pairs per mm, according to WELCH (1968, p. 492), is relatively common. The highest resolution in his test was 475 line pairs per mm.

A third factor often considerably affecting the resolving power of photographs is picture motion. Its effect on the resolving power can be estimated by assuming that it is the only limiting factor. The resolving power of a photograph can be shown approximately by an equation (cf. SORJONEN & HAKKARAINEN 1971, p. 55):

$$\frac{1}{R} = \frac{1}{R_1^n} + \frac{1}{R_2^n} + \frac{1}{R_3^n} + \frac{1}{R_4^n}$$

where R = the resolving power of the photograph, line pairs per mm, R_1 = that of the film, R_2 = that of the camera, R_3 = that presupposed by picture motion and R_4 = that permitted by vibration. The value of n is between 1 and 2 and is obtained empirically. Another way of estimating R is by means of the modulation transfer function (see e.g. BROCK 1968). The most reliable estimation can be obtained with photography of specially built test fields. For photographs for practical use in Finland, the resolving power usually lies within the limits 15—40 line pairs/mm (HAKKARAINEN 1970, p. 114; HAAPAMÄKI 1971, pp. 33—36).

The resolving power of the normal untrained human eye is about 6 line pairs per mm. The relationship of this to the above figures shows that information obtainable from photography carried out with good techniques can be greatly increased by viewing the photos with magnifying equipment.

The most serious adverse factor affecting the interpretation of aerial photos is apparently the presence of air or any other intermediate substance between the object to be photographed and the lens of the aerial camera. The molecules and other particles in air (grains of water and dust) scatter and absorb radiation energy reflected from the target and reduce contrasts between the details of the terrain on the photo. With reduced contrasts the resolving power of the photo decreases. These adverse effects can be reduced by correct choice of the time of photography (weather conditions) and filters.

Photography for forestry purposes to date has almost exclusively been black and white. Colour photography in the range of both visible and near-infra waves is, however, becoming more common. This type of photography

can provide much more reliable information than black and white aerial photos, especially in the recognition of targets. On the other hand, colour photographs are somewhat more expensive (COOPER and SMITH 1966). Nor have their advantages always proved convincing in photo interpretation for forestry (LACKNER 1966; POSO, KEIL & HONKANEN 1968, p. 17).

The scale of photography and of photographs used in interpretation for forestry purposes has mostly ranged from 1: 10 000 to 1: 60 000. According to several authors (e.g. POPE 1957; SMITH, LEE & DOBIE 1960; LACKNER 1966; POSO *et al.* 1968), the scale, especially in the range from 1: 10 000 to 1: 30 000, has been of relatively little importance compared with other factors (the interpreter's skill and insight into forest classifications).

In the improvement of inventory methods, the potential uses of large-scale aerial photos 1 : 800—1 : 4 000) has also been investigated (ALDRICH, BAILEY & HELLER 1959; SAYN-WITTGENSTEIN & ALDRED 1967; ALDRED & KIPPEN 1967). Full coverage of a forest area would often be too expensive. For this reason photography of targets selected by sampling must be given priority.

In contrast to large-scale aerial photos, extremely small-scale photos taken by earth-orbiting satellites can also be utilized for forest inventories. They are helpful, for example, when the volumes of relatively large areas are estimated. An experiment made in Finland with an available photograph from the meteorological satellite Essa 8, taken from a heigh of 1 500 km, showed the existence of a distinct correlation ($r = 0.84$) between the characteristics estimated from the satellite picture and the regional mean volumes (KUUSELA & POSO 1970).

Forest targets are usually viewed using lens stereoscopes with a magnifying power of 2—4 times, or mirror stereoscopes with a magnifying power of 1—6 times. Other auxiliaries commonly used in the interpretation are parallax bars to measure tree heights, various scales, usually printed on transparent film, for determination of crown-closure percentage, aerial volume tables, and stereograms marked on a print and measured in the field for the interpretation of all stand characteristics. Field visits, information obtained from maps of by other means and ocular reconnaissance, e.g. by aircraft, are additional aids in interpretation.

Automation of interpretation and the analytical interpretation methods (use of element combinations measured from aerial photos) are receiving increasing attention in forestry. If two or more photographs of the same targets are taken with different wave-length bands (multispectral photography), the targets can be classified on the basis of the criterion combinations visible in the different photographs (e.g. LAUER 1968). The analytical method can also be applied to colour photographs with the aid of filters (KUITTINEN 1971).

123. Correlation between photo-interpreted and field-measured observations

The interest in applying aerial photographs to forest inventories originated in a series of studies concerning the precision of photo-interpreted stand characteristics. Most interest was given to stand volume and tree-species identification. Parameters such as site, treatment class, age class, etc., based on stand classifications, have also been studied. In time, with progress in studies, more interest has been directed to the estimation of single trees on large-scale photographs and the identification of targets by using multiband techniques and colour photographs.

The use of aerial volume tables is common, especially in North America and in the tropical countries. With the help of these tables, the directly measurable stand or tree characteristics can be transformed into a desirable form. In North European countries, this practice has not a great importance. Instead of using aerial volume tables, the precision of the interpretation of all stand characteristics can be improved by stereograms, maps, field reconnaissance, etc. It seems justified to conclude that in North European conditions no significant differences exist in the precision obtained by these two methods (cf. NYYSSÖNEN & POSO 1962, p. 12).

The standard of photo interpretation is the result of several factors. Large variations in precision (and correlation) from case to case are therefore natural. Fig. 122.1 shows a number of factors affecting the correlation in a box diagram, where the arrows indicate the assumed interdependencies. In North European forestry, use has mainly been made of aerial photos of scales ranging from 1: 10 000 to 1: 60 000. The precision of volumes (m^3/ha) interpreted from aerial photos, presented as a percentage of the standard deviation from the mean, has been generally found to be about ± 30 % (NYYSSÖNEN 1955; TÖRNSTRÖM 1960; SANDBERG 1961, 1963; NYYSSÖNEN & POSO 1962; NYYSSÖNEN *et al.* 1968). The percentage tends to become smaller the higher the mean volume. In other terms the quality of photo interpretation can be expressed by a correlation coefficient. In most experiments, the coefficient r, presenting the correlation between photo-interpreted and field-measured volume in m^3/ha, shows the values ranging from 0.65 to 0.85. In some small experiments, values as high as 0.90—0.95 have been encountered.

Correlation in tree-species estimation is greatly affected by the scale and season of photography, the type of the target and the type of film. It is often difficult even to distinguish a conifer from a broad-leaved tree on the black-and-white panchromatic aerial photographs taken in the middle of the summer with scales ranging from 1: 10 000 to 1: 60 000. However, these kinds of photos are those most commonly used in forestry. In Finnish experiments, the main tree species of a stand has been correctly estimated in about three-

quarters of the targets (only three species). Stands with mixed tree species cause, of course, the most difficulties (NYYSSÖNEN *et al.* 1968, p. 16).

Correlation in tree-species identification is increased by carrying out the panchromatic black-and-white photography in early summer or in autumn, or by using panchromatic colour photography (HELLER, DOVERSPIKE & ALDRICH 1964), or infra-red colour photography (POSO *et al.* 1968). A deciduous tree is readily distinguishable from conifers even on black-and-white mid-summer photographs, provided the photographs are taken on film sensitive to infra-red wave lengths. Scale, however, has the greatest effect on correlation (POPE 1957, p. 872; HELLER *et al.* 1964, p. 9; POSO *et al.* 1968, p. 16). With large scales, the morphological features of individual trees become decisive.

Photo- and field-estimated treatment and age classes usually show distinct correlation. In an experiment (NYYSSÖNEN *et al.* 1968, p. 17), however, it was found that only about 30 % of the targets subject to treatment-class estimation had complete correspondence. It should be borne in mind that the determination of treatment class, even in the field, is often subjective, allowing big differences between the field estimates of different persons. This is especially the case in forests which have been treated with selection cuttings.

In Finland the estimation of site characteristics is based on the composition of ground vegetation, especially on the presence or absence of indicator plants (CAJANDER 1909; KUUSELA & SALMINEN 1969, pp. 20—25). As the photos show the ground vegetation incompletely, the estimation from photographs has to be based on trees and topography. Applying black-and-white 1: 10 000 photographs, SANDBERG (1963, pp. 16—17) found in his experiments the correlation in site estimation satisfactory in Sweden. Similar experiences have been reported by POSO *et al.* (1968, p. 13) in Finland and SMITH & BAJZAK (1961) in Canada.

124. Statistical frame

Where the accuracy of photo interpretation is not sufficient, multi-phase sampling has to be applied. The simplest form is double sampling. The first phase consists of a large photo-plot sample and the second phase of a field-plot sample drawn from the first-phase sample. The subject of this chapter is limited to the illustration of double-sampling methods as described by COCHRAN (1963, pp. 327—354).

The prerequisites for the feasible application of double sampling are that sufficient correlation exists between characteristics interpreted from aerial photographs and measured in the field and that the unit cost of a photo-interpreted plot is sufficiently less than that of a field-measured one. In

statistical presentations and assessments of the method, it has usually been supposed that random selection has been applied in both phases of the double sampling.

With regard to the form of application, double sampling is divided here into four methods:

(1) double sampling for stratification
(2) » regression
(3) » ratio
(4) » partial replacement

The fourth method has been included in the list although its scope is much larger than that of the first three methods, which, in fact, can be regarded as special cases of the fourth method. The method can be useful in continuous forest inventories, as some of the plots of an earlier inventory are measured again. The method can be connected with the application of aerial photographs as shown, for example, by BICKFORD *et al.* (1963).

The first three methods are described by equations. The estimators of means (e.g. m^3/ha) for the methods are:

$$\bar{y}_{st} = \sum_{k}^{L} w_k \bar{y}_k \qquad \text{(cf. COCHRAN 1963, p. 328)}$$

$$\bar{y}_{lr} = \bar{y} + b\,(\bar{x}' - \bar{x}) \qquad \text{(cf. COCHRAN 1963, p. 334)}$$

$$\bar{y}_R = \frac{\bar{y}}{\bar{x}}\,\bar{x}' \qquad \text{(cf. COCHRAN 1963, p. 339)}$$

where

$\bar{y}_{st}$ = estimate of mean for the population
$\bar{y}_{lr}$ = »
$\bar{y}_R$ = »
w_k = estimated proportion of stratum k
$\bar{y}_k$ = estimated mean for stratum k
$\bar{y}$ = mean of all field-sample units
$\bar{x}$ = mean of those photo-sample units belonging to the set of photo plots selected for field checking
$\bar{x}'$ = mean of all photo-sample units
b = coefficient of regression, y over x

13. Application of aerial photographs for forest inventories

There is a wide diversity of ways in which aerial photographs can be applied to forest inventories. Suggestions for their classification have been made, for example, by HUSCH (1971, p. 5) and HILDEBRANDT (1962). Only two kinds of methods are discussed in this connection: methods based on direct use of photo interpretation and methods based on double sampling.

The application of *methods based on direct use of photo interpretation* can be considered feasible only if the accuracy of interpretation is regarded as sufficient. The simplest application of this kind is probably the use of aerial photographs as map replacements for the location of sampling units in the field. This kind of application is practiced, for example, in the Swedish national forest inventories and in the inventories of the U. S. Pacific Northwest Region (HILDEBRANDT 1961, 1962).

Land-use classes can often be reliably estimated from aerial photos, which are therefore well adapted for the estimation of proportions (NYYSSÖNEN *et al.* 1968) or for elimination of non-forestry land from the region undergoing the inventory, as is done, for example, in the southern states of the USA (HILDEBRANDT 1962). Aerial photographs have also been used in connection with field work in the Finnish national forest inventories for interpreting and measuring water, agricultural and some treeless swamp areas along the tracts in the cases where the basic maps (1: 20 000) have not been available. If a target can be reliably interpreted from aerial photos, its estimation in the field is no longer required. An additional possibility which has had some experimental use in Finland (ILVESSALO 1956, p. 206) is to estimate from aerial photographs, without field-based corrections, only the targets difficult of access. This means that direct use of aerial-photo interpretation has been applied to a part of the population.

Another example of the partial use of direct photo interpretations is from the Soviet Union. In the forests of certain forestry-intensity classes, the inventory lines are perambulated in the field at fixed intervals, from which the desirable estimates are made. The areas between the lines are then estimated directly from aerial photographs by compartments (HILDEBRANDT 1962). In this method, the operational sequance is the reverse of that mentioned on page 7, in which compartments are delineated with the aid of aerial photographs and their estimation is based entirely on field work.

In extensive surveys, the inventory can be based totally on the direct use of photo interpretation. This kind of inventory has been applied, for example, in Canada (BICKERSTAFF & HIRVONEN 1969), Alaska and the Soviet Union (HILDEBRANDT 1962). As facilitating and corroborative aids for interpretation, the use of stereograms, ocular air surveys, etc. are often feasible. Even the general picture which can be achieved of the area through aerial

photographs can be considered one type of result of using direct photo interpretation for inventory purposes.

If the precision obtained by the methods based on direct use of photo interpretation is not regarded as satisfactory, *methods based on double sampling* (p. 15) should be used to reduce the amount and cost of field work. Of these methods, double sampling for stratification has been applied almost exclusively. Most uses of the method are concentrated in North America and tropical countries.

Double sampling for stratification can be divided into two parts according to the sampling unit applied. When a compartment delineated on a photograph is used, the method is termed here *double sampling for stratification with compartments* abbreviated *d-s/*$_{\text{comp.}}$ In addition to forest inventory, the method serves forest-mapping purposes. It has been applied extensively in Canada (SEELY 1964), and to some extent in the USA — in the Pacific Northwest Region (FERREE 1953), Minnesota (KNOX 1956) and Maine (YOUNG, CALL & TRYON 1963) — and in many tropical inventories, e.g. in Brazil, Cambodia, Ceylon, Sudan, Thailand and Uganda (LOETSCH 1957; NYYSSÖNEN 1962).

The method *d-s/*$_{\text{comp.}}$ involves numerous potential variations in its operational phases. Compartments are usually drawn with a minimum size. This usually varies within the limits of 2—40 ha (5—100 acres). Several alternatives are used in field work (cf. SEELY 1961, 1964). Usually the required field data are collected from randomly or systematically located sample plots for the compartments belonging to the field sample.

The first phase of the sample usually consists of all the compartments of the inventory area. The compartments are delineated on photographs and then stratified by photo interpretation. The proportions of the strata can be measured accurately. A sample of compartments is selected from each strata to be measured in the field. The major drawback of the method is that the delineation of the compartments and calculation of their area are time-consuming and expensive and that, owing to the minimum-area rule, considerable variation may be present inside the compartments.

In order to avoid the drawbacks stated for the method *d-s/*$_{\text{comp.}}$, BICKFORD (1952) began to apply double sampling with sample plots to forest inventory according to principles presented first by NEYMAN (1938). The method is termed here *double sampling for stratification with sample plots* and it is abbreviated *d-s/*$_{\text{plots}}$. He found that the application of *d-s/*$_{\text{comp.}}$ was not feasible in the Northeast Region of the USA because the forests there were more heterogeneous than in Canada and the delineation of sufficiently uniform compartments therefore would have been difficult.

The use of plots in double sampling has subsequently become much more widespread. LANGLEY (1962), for example, found that it was considerably

more advantageous to use plots than compartments. Double sampling with plots is used not only in the Northeast Region but also in the Pacific Southwest Region (LANGLEY 1962) and in the North-Central and Intermountain Regions (HILDEBRANDT 1962). One-acre circular sample plots are currently being used in the U.S. photo interpretation. One photo plot may consist of a cluster of ten Bitterlich points mechanically arranged within a circular acre (BICKFORD 1972, communication by letter). The method is applied to a smaller extent in Sweden, as has been illustrated for example by HEDLUND (1966).

LANGLEY (1962, p. 2) compared $d\text{-}s/_{\text{plots}}$ with $d\text{-}s/_{\text{comp.}}$. He listed a number of points in favour of the former method:

(1) The use of sample plots in aerial photo interpretation permits selection of ground sample plots by random sampling.
(2) The classification of sample plots is easier and more reliable.
(3) Calculation of results is easier.
(4) Interpretation of sample plots is faster and cheaper than that of compartments.

BICKFORD *et al.* (1963, pp. 826—827) described $d\text{-}s/_{\text{plots}}$ as applied in the Northeast Region of the USA: »A large number of points are put on aerial photographs systematically. Each is photo-interpreted and given a volume classification (that is, assigned to a photo-volume stratum) based on the estimated amount of timber on the acre surrounding the point. A certain number of these points from each stratum are then randomly selected for ground examination. These ground plots are located, occupied, and classified according to various criteria (for example, forest type, stocking); and trees in them are measured and classified for volume, species, and quality class, as usual in timber cruising. Mean and variance for each attribute are obtained for each photo stratum from its subsample.

»More precisely, double sampling means: A large number (N) of points or plots on aerial photographs are inexpensively examined, measured, and classified (i.e., stratified); a subsample (n) of these plots is occupied and observed on the ground; and the data are then appropriately combined to provide estimates of total current volume and other statistics. The first phase of the double sample is the photo phase, for which the cost per plot of observation is low. The second phase is the ground phase, for which the cost per plot is rather high.«

Double sampling for stratification with plots proved superior in the U.S. Northeast Region to other methods based on plot sampling. BICKFORD (1961) considered that to make the use of this method possible a specific aerial photography carried out for the purpose may even prove an economic proposition. If photography has already been carried out, the use of this method is always

advantageous. In BICKFORD's studies, the photo interpreters were skilled and the aerial photos of good quality. »With older photographs, changes due to cutting, fire, wind, growth, etc., tend to reduce differences among strata means and to inflate variation within strata. However, it is easy to overstress the impact of these changes» (BICKFORD 1961, p. 763).

Experiences of the use of double sampling based on stratification of plots have not everywhere been as favourable as those quoted above. In Middle Ottawa, Canada, KENDALL & SAYN-WITTGENSTEIN (1961) compared the different methods based on plot sampling and found that, with aerial-photo stratification, the degree of efficiency for volume was only 1.28 against simple random sampling. In Finland, NYYSSÖNEN *et al.* (1968) found by experiment that the main merit of the aerial-photo plot stratification was obtained in the estimation of land-use classes. For the estimation of the internal parameters of forest land, the use of aerial photos did not bring any distinct advantage. In the best cases, the number of field-sample plots might have been reduced by half for estimating the mean volume of forest land. In many cases, the additional cost of aerial-photo interpretation could not be offset by reduced costs of field work. Similar conclusions have also been published by GROSSMANN & WOLFF (1963) and by LOETSCH (1963).

The other method referred to in the statistical frame (p. 15) was double sampling for regression. This method has been recommended especially by ROGERS (1959, 1960, 1961), who experimented with it in Iran. The method has not, however, gained much popularity in practice. The reason may be that it is not sufficiently flexible for calculating a large diversity of parameters. It might be possible, however, to apply its underlying idea beneficially to the estimation of parameters for different strata within the method of double sampling for stratification (cf. COCHRAN 1963, pp. 200—204).

An application of double sampling for stratification combined with partial replacement of plots appears to have been first proposed in forestry by BICKFORD in 1959 (NYYSSÖNEN 1967, p. 197). The combined method has been used in the inventories of the Northeast Region. BICKFORD, MAYER & WARE (1963, p. 832) reported that with this design the number of field plots can be reduced by about two-thirds and that of photo plots by more than half the number required for ordinary double sampling for stratification.

According to BICKFORD (communication by letter 1970), »the initial survey of the Northeast Region was begun in 1946 and completed in 1958. At this first occasion for each of the several states, the photographs were used to define strata. At the second occasion some of the ground plots from the first occasion were remeasured to provide a first estimate at the second occasion. Another estimate was obtained by use of new aerial photographs, new photo plots, and new ground plots in exactly the same manner as was employed initially. These two estimates were then combined, weighting

by variance reciprocals, to estimate the desired quantities at the second occasion» (cf. COCHRAN 1963, pp. 341—344).

More than two occasions can also be used. According to BICKFORD, »the third occasion offers a variety of alternatives that have not been thoroughly investigated. One possibility would be to remeasure some ground plots from each of the two previous sets and to obtain a third estimate from new photographs and new plots. The three independent estimates would be combined in a manner parallel to that for two. Multiple regression techniques are also available, as has been pointed out by CUNIA (1965).»

14. Preference of various inventory methods

An appraisal of an inventory method requires comparisons. The characteristics on the basis of which the appraisal of a method in respect of others is possible can be termed preference criteria. The most important considered here are: (1) efficiency, (2) computational flexibility, (3) flexibility in data collection, and (4) expertise required. The content of each of these terms is outlined below.

The *efficiency* of an inventory method is best determined separately for each parameter subject to inventory. For total efficiency, some kind of pooling procedure should be applied. This, of course, presupposes that the objectives of the inventory are defined and the estimates can be weighted. This, again, means that the value of an estimate should be related to precision.

The definition of the efficiency of a method is illustrated by assuming that a single parameter, $\overline{Y}$ (e.g. mean volume of growing stock), is to be estimated. The efficiency of a method *a* in respect of another method *b* in estimating $\overline{Y}$ is expressed here in the form:

$$t_{\bar{y}(a/b)} = V_{\bar{y}(b)} / V_{\bar{y}(a)} \;\Big|\; C_{\bar{y}(a)} = C_{\bar{y}(b)}$$

where $V_{\bar{y}}$ = variance of the mean and
$C_{\bar{y}}$ = the total cost of the inventory method for the estimate of $\bar{y}$

The condition $C_{\bar{y}(a)} = C_{\bar{y}(b)}$ means that the estimates $\bar{y}_{(a)}$ and $\bar{y}_{(b)}$ should be based on equal total costs. A change in the level of total cost probably has some effect on the efficiency. Accordingly, it can be possible that, at some level of total cost, method *a* is more efficient than method *b* and, at some other level of total cost, the relation is reversed.

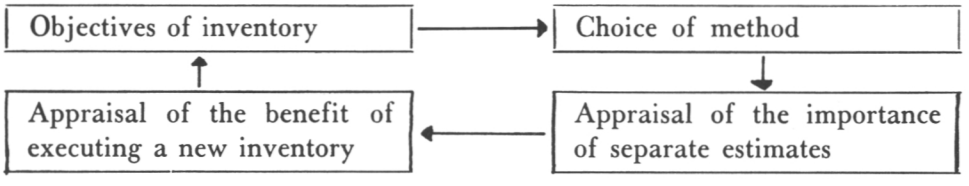
Flexibility in computation refers to the ease with which the results of all potential use can be calculated. Thus, the flexibility is good if, for example, it can be freely decided what kind of tables will be produced, and poor if the classifications to be produced in tables are fixed once the sample plots have been measured. When the confidence of the results, after modification of the tables, is reduced drastically owing to the method used, the flexibility is also considered poor.

Flexibility in computation is especially important if all the tables needed cannot yet be foreseen at the time the inventory is planned. This is true, for example, of the national inventories. On the basis of the materials collected in Finland by the Fifth National Forest Inventory (1964—1970), the standard results were calculated for 20 regions (26 tables for each region, see e.g. KUUSELA & SALOVAARA 1971). By request from outside interests, the number of calculations was afterwards enlarged to about 600 regions.

Flexibility in data collection refers to the possibility of arranging the different phases of work required for data-collection flexibly and thus allowing the efficient use of personnel in the perspective of one year. Inventory methods based on field work alone are often inflexible if, owing to the natural conditions, the field work is seasonal (e.g. due to winter or rainy seasons). In Finland, for example, the field-work season lasts a maximum of 5 months. The methods permitting efficient work throughout the year are flexible. The flexibility in data collection is of considerable importance, especially if field work is to be done annually with permanently employed personnel.

Expertise means know-how concerning the potential methods of inventory. The more complicated the methods, the more demanding the training required and the higher the wages and salaries payable. If expertise is lacking, only the simplest inventory methods can be used, i.e. those based on field work alone.

Decision-making for the selection of a inventory method must be understood as a part of large system (cf. PALO 1971, p. 23), in which, in addition to the criteria listed, all influential factors are considered: objectives, restrictions, etc. For example, shortage of expertise need not necessarily lead to a method being discarded. An alternative is training, in which case the decision may have an influence extending beyond one single inventory. The background system for the choice of the method can be illustrated by a diagram in which arrows indicate the assumed sequence of various decisions in the system of continuous forest inventory.



The appraisal of the importance of individual estimates in matching the objectives is not easy. Some of the estimates are strongly intercorrelated. Thus, it may be possible to a large extent to substitute one estimate for another. This leads to the conclusion that instead of individual estimates it would be feasible to use sets of intercorrelated estimates for appraisals. A technique based on the calculation of sum vectors which aim towards the objective might be applicable. This technique, with practical solutions, has been described in sociology by MYLLYNEN & RAJALA (1970, pp. 33—37).

Previous studies comparing various inventory methods have not worked on a multiple-objective basis. Usually, the main interest has been focused on volume estimates. Volume and forest-land area are commonly regarded as the most important parameters to be estimated (cf. BICKFORD 1953, p. 1; NERSTEN 1965, p. 156). However, in the northern countries of Europe, greatly detailed information has traditionally been expected from the large forest inventories (KUUSELA & ERVASTI 1969, p. 25). Against this background, and thinking of the possible application of aerial photographs, one cannot be very sure which objectives are the minimum factors in planning the design and sample sizes.

15. Initiative and the object of the study

It is clear that circumstances are becoming more favourable for the application of aerial photographs for forest inventory in the North European countries, where the use of photos for this purpose has so far been of minor importance. Finnish research establishments in this field were naturally interested in mapping the situation and in finding the most suitable ways of application. As the cost of inventories is high [the annual cost of the Finnish national forest inventory amounted to about 450 000 Fmk (about 100 000 dollars)], even minor improvements in inventory methods can be of substantial economic importance.

According to NYYSSÖNEN *et al.* (1968), double sampling for stratification could not be recommended for immediate practical use in Finnish forestry. Also other methods applied elsewhere did not seem more promising. A critique of the methods is presented in tabular form from the point of view of the Finnish national forest inventory.

Criterion	d-s/comp.	d-s/plots	d-s/regr.[1]
Efficiency	low	?	?
Flexibility in computation	low	low	low
Flexibility in data collection	high	high	high
Need for expertise	high	high	high

[1]) d-s/regr. = double sampling for regression

The efficiency of double sampling has been itemized in two cases with a question mark. The final answer depends greatly on the objectives of the inventory, i.e. what weights are to be given to the precision of each parameter subject to inventory. The methods based on double sampling have usually been more efficient than one-phase field sampling in estimating land-use classes and total volume. In respect of very detailed parameters, the situation is reversed. This is a serious handicap, especially in the Finnish national forest inventories where the importance of detailed parameters obtained by inventory is regarded highly.

In order to avoid or at least to diminish the handicaps inherent in these double-sampling methods when applied to the Finnish national forest inventories, a new approach has been devised for using aerial photographs as a part of double sampling. It resulted in a method termed the *grouping method* according to one of its operational phases. This study aims first at description (Chapter 2) and second at tests (Chapters 3—6) of the method. The tests and the consequent conclusions and suggestions mainly relate to the conditions of the Finnish national forest inventories.

2. DESCRIPTION OF THE GROUPING METHOD

21. Verbal presentation

The grouping method is based on double sampling. The sampling unit was assumed to be a plot although there is no absolute reason why it could not be a compartment. The first phase consists of a large number of plots (photo plots) interpreted from aerial photographs as in double sampling for stratification or regression. The photo plots are grouped into as homogeneous groups as possible according to all of the interpreted characteristics. From each group, one plot is then selected randomly to be measured in the field. The set of resulting plots (field plots) supplied with the necessary field measurements forms the second phase of the grouping method.

Complete results are calculated for each field plot. These are then extended to furnish all the photo plots of the respective groups. However, only that data which describes growing stock and site-fertility, and other characteristics like them, is extended. Data obtained from maps can be directed permanently for each photo plot. A great benefit of the procedure is that each photo plot receives formally complete data records. This makes it possible to treat every photo plot as an independent computational unit, thereby giving the grouping method a very good computational flexibility. The method is illustrated and compared with other methods in Fig. 21.1.

22. Statistical description

221. Population

The total area subject to forest inventory is assumed to be known and to consist of A hectares. It is also assumed that the aerial photographs cover the entire population. In order to consider a finite but very large population, the total area A is assumed to be divided into a grid consisting of a very large number of uniform squares, 10 by 10 metres, for instance. This grid is to be superimposed on the aerial photos as well as on the ground.

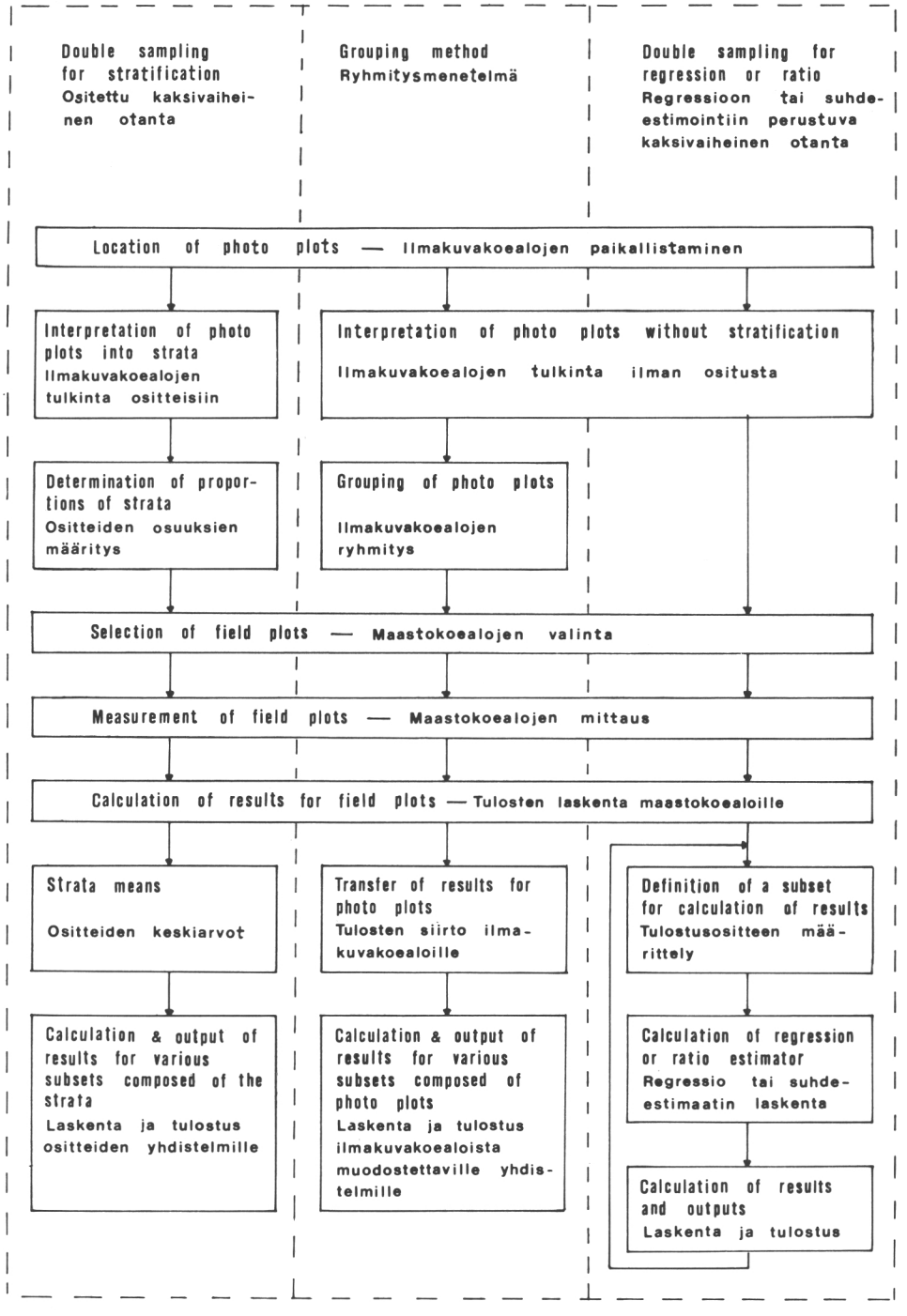


Fig. 21.1. The grouping method compared with other two-phase inventory methods
Kuva 21.1. Ryhmitysmenetelmän ja muiden kaksivaiheisten otantamenetelmien vertailu

The population consists of N squares, each represented by a point. The number of points on the aerial photos and on the ground is assumed equal, with perfect coincidence of respective photo and field points. The population subdivided into m groups with a total of N_k points in the kth group. The proportion of population points in tyhe k^{th} group is $\pi_k = N_k/N$.

222. Population parameters

The definitions and notations are mainly based on the handwritten manuscript by HORWITZ (1959):

A = total area subject to forest inventory (known)
N = total number of points in entire population (known)
m = total number of groups
N_k = total number of points in the kth group of the population (unknown)
π_k = N_k/N = proportion of population in k^{th} group (unknown)
y_{ki} = some measure of the population point number i from k^{th} group (e.g. m^3/ha or proportion of an area subset on the point)

$$\Theta_k = \sum_i^{N_k} \frac{y_{ki}}{N_k} = \text{true mean of the } k\underline{\text{th}} \text{ group of the population}$$

$$\Theta = \sum_k^m \pi_k \Theta_k = \sum_k^m \frac{N_k}{N} \sum_i^{N_k} \frac{y_{ki}}{N_k} = \frac{1}{N} \sum_k^m \sum_i^{N_k} y_{ki}$$

= true mean of entire population

$$\sigma_k^2 = \frac{1}{N_k} \sum_i^{N_k} (y_{ki} - \Theta_k)^2 = \text{true variance of the measure } y_{ki} \text{ of the } k\underline{\text{th}} \text{ group of the population}$$

$$\sigma^2 = \frac{1}{N} \sum_k^m \sum_i^{N_k} (y_{ki} - \Theta)^2 = \text{overall population variance}$$

$$= \sum_k^m \pi_k \sigma_k^2 + \sum_k^m \pi_k (\Theta_k - \Theta)^2$$

223. Estimators

2231. Sampling procedure

A systematic sample of n plots is taken from the aerial photos. These n plots are then grouped into m homogeneous groups in respect of all the photo interpretations. In group number k there are n_k photo plots. A random subsample of m_k equals 1 and thus the size of subsample equals the number of groups. For each of the plots of the subsample, some measures of direct interest are made on the ground.

2232. Sample notations

List of symbols

- A = total area subject to forest inventory
- n = sample size of first-phase sampling, i.e. number of photo plots in the sample
- m = sample size of second-phase sampling, i.e. number of field plots in the subsample drawn from the first-phase sample = number of groups
- A_i = area represented by one photo sample plot i
- n_i = number of photo sample plots in area A_i
- n_k = number of photo sample plots in group k
- m_k = number of field sample plots in group k
- A_j = area of subset j (j may be an index for site class, for example)
- n_j = number of photo sample plots in area A_j
- m' = number of group sets
- n_k' = number of photo sample plots in group set k'
- $m_{k'}$ = number of field sample plots in group set k'
- p_k = proportion of an area class observed on a field plot selected from group k
- y_k = observation of quantitative character on a field plot selected from group k
- x_i = an observation (e.g. volume of growing stock) made on photo sample plot i
- y_i = observation of quantitative character measured in the field and extended to a photo plot i
- p = sample mean of area proportion (e.g. proportion of forest land)
- $\bar{y}$ = sample mean of quantitative character (e.g. mean volume of forest land)
- v_p = estimated sampling variance of p

$v_{\bar{y}}$ = estimated sampling variance of $\bar{y}$

In what follows

m_k = 1

p_k = 1 if the field plot belongs totally to the subset under investigation
= 0 if no part of the field plot belongs to the subset under investigation
= between 0 and 1 if some part of the plot belongs to the subset under investigation

y_i = constant for all photo plots belonging to the same group

2233. Area proportions and means

Since the total area A is assumed to be known, the estimate of the area A_j can be written as

$$a_j = p_j A \qquad (2233.1)$$

where p_j is an estimator of A_j/A. Because every photo plot is supplied with formally complete data, the estimator p_j can obviously be written as

$$p_j = n_j/n \qquad (2233.2)$$

The calculation of n_j is illustrated by Figure 2233.1.

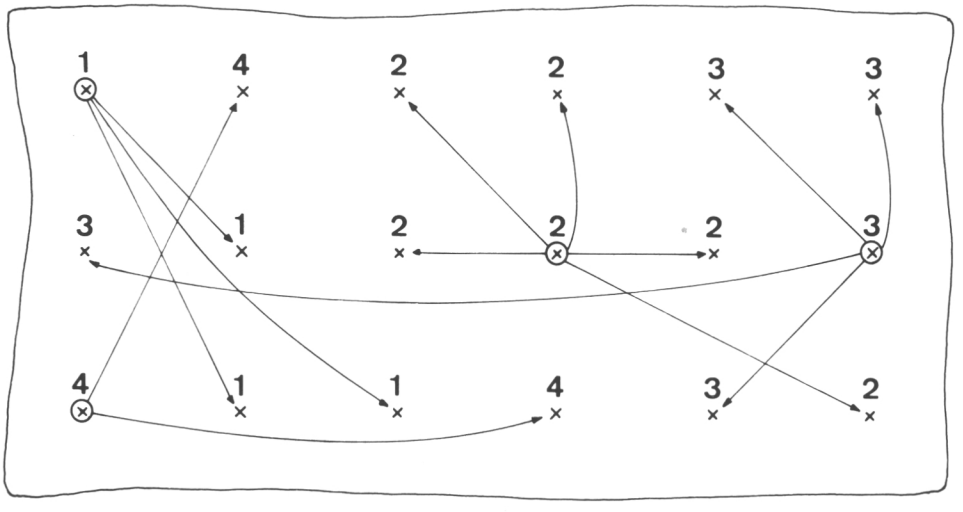


Fig. 2233.1. Illustration of the estimation of area proportions and means
Kuva 2233.1. Pinta-alaluokkien ja keskiarvojen estimoinnin havainnollistaminen

The figure is dependent on the following assumptions:

(1) The 18 photo sample plots are placed over the area equidistantly.
(2) The photo sample plots have been grouped on the basis of photo interpretation into 4 homogeneous groups. Each photo plot is supplied with the group number.
(3) From each group one sample plot (that surrounded by a circle) is selected to be measured in the field.
(4) After the field sample plots have been measured and the calculations have been performed for each of them, the results have been extended to all of the photo sample plots as indicated by the arrows. Thus, each photo sample plot is supplied with formally complete data.
(5) The field plot representing group 2 is the only one observed to be on subset j and the field plot does not include any other subset.

It follows from the illustration and especially from assumption 5 that $n_j = 6$. Accordingly, $p_j = 6/18 = 1/3$.

The estimator of the mean of a quantitative character for a subset j can obviously be written as (see Fig. 2233.1)

$$\bar{y}_j = \sum_i^n y_{ji} / n_j \qquad (2233.3)$$

where

y_{ji} = observation of a quantitative character expanded to photo sample plot i belonging to subset j. The value of y_{ji} is considered zero if the plot i doesn't belong to subset j.

In a special case, when subset j consists of the whole inventory area, i.e. the mean of the total area is considered, the estimator can be presented as

$$\bar{y} = \sum_i^n y_i / n \qquad (2233.4)$$

2234. Variances

Application of the variance estimators derived for double sampling for stratification is not possible for the grouping method without special arrange-

ments, as only one field sample plot is drawn from each group. Therefore the variance estimators are based on the construction of group sets. Separate groups are put together to form homogeneous sets. The construction should be done separately for each parameter whose variance is to be estimated. For example, for the proportion of forest land, all the groups interpreted as forest land can be put into the same group set. If the proportion of site-fertility class is in question, only those groups interpreted equally or close to each other with regard to site fertility are put together. The estimator is probably a little biased and leads to too large variances. This is because the assumption that the group sets are as homogeneous as the groups may not hold good.

First, emphasis is given to the *estimation of variances for area proportions.* It is obvious that many groups have exactly similar photo estimations for a specific area class. For example, ten groups may be homogeneous as regards site-fertility class j. In estimating the variance of the proportion p_j, those groups can be placed into the same set k'. Equally, all the other groups which seem, according to photo interpretations, to be close to each other in respect of whether or not they are site-fertility class j are put into the same group set. Assuming that the true variances within groups are equal by group sets, the technique of double sampling for stratification can be applied to estimating the variance (e.g. COCHRAN 1963 p. 333):

$$v_p = \frac{n}{n-1} \sum_{k'}^{m'} \left[(w_{k'}^2 - \frac{w_{k'}}{n}) \frac{p_{k'} q_{k'}}{m_{k'} - 1} + \frac{w_{k'} (p_{k'} - p)^2}{n} \right] \qquad (2234.1)$$

where

$w_{k'} = n_{k'}/n$ and

$p_{k'} = n_{jk'}/n_{k'}$,

with

$n_{k'}$ = number of photo plots in group set k' and

$n_{jk'}$ = number of photo plots in group set k' belonging to area class j.

The finite multiplier was excluded from the above equation. In almost all cases, the equation can be simplified further (COCHRAN 1963, p. 333) into

$$v_p \approx \sum_{k'}^{m'} \frac{w_{k'}^2 p_{k'} q_{k'}}{m_{k'} - 1} + \frac{1}{n} \sum_{k'}^{m'} w_{k'} (p_{k'} - p)^2 \qquad (2234.2)$$

In double sampling for stratification, the concepts of variance within and between strata are used to indicate the source of variation. When the strata are regarded as groups, the concepts can be applied also to the grouping method. Equation 2234.2 is rewritten in the following form:

$$v_p = \frac{v_1}{m} + \frac{v_2}{n} \qquad (2234.3)$$

where

$$v_1 = m \sum_{k'}^{m'} \frac{w_{k'}{}^2 p_{k'} q_{k'}}{m_{k'} - 1} \qquad (2234.4)$$

= variance within groups and

$$v_2 = \sum_{k'}^{m'} w_{k'} (p_{k'} - p)^2 \qquad (2234.5)$$

= variance between groups.

Equation 2234.3, as Equations 2234.1 and 2234.2, is constructed on the assumption that the first-phase sample (photo-plot sample) is drawn by random sampling. As in the grouping method, systematic sampling was assumed to be applied; Equation 2234.3 is converted to

$$v_p = \frac{v_1}{m} + g\frac{v_2}{n} \qquad (2234.6)$$

where

g = correction coefficient resulting from the systematic location of photo sample plots.

The last term of Equation 2234.6 is conversely related to n. This means that the larger the number of photo plots the better the representativeness of the photo-plot sample. It is, however, clear that the degree of representativeness can also be affected by the location of photo sample plots. Photo plots placed systematically represent the population usually better than those placed at random. Therefore the value of coefficient g is usually less than one in the case of systematic sampling. Derived from the above, the n plots placed at random represent the photo-plot population as precisely as gn plots placed systematically. The philosophy underlying the estimation of coefficient g is illustrated with the aid of a schematic figure.

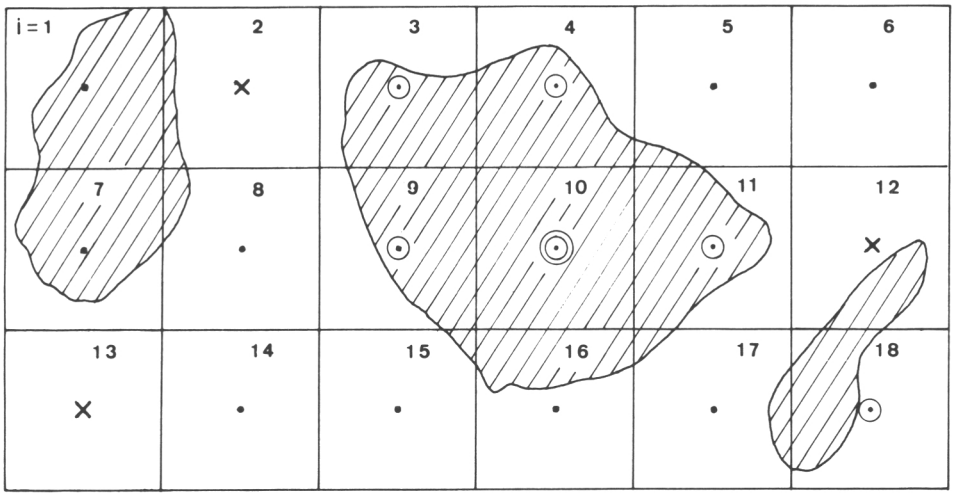


Fig. 2234.1. Illustration of the estimation of variances
Kuva 2234.1. Varianssien estimoinnin havainnollistaminen

Assumptions included in the figure:

(1) The 18 photo plots are placed over the area by means of a square grid (central points).
(2) The area A_i represented by a photo sample plot is an area of a square.
(3) $A_i = A / 18$.
(4) Area A_j to be estimated is shaded by oblique lines (hypothetical: A_j cannot be known in practice).
(5) The six photo sample plots surrounded by a circle belong to a specific group.
(6) From the specific group the plot with two circles has been drawn by random sampling to be measured in the field.
(7) The field sample plots drawn from other groups are marked by crosses.

It follows from Figure 2234.1 that the right proportion of A_j is about 7/18. The estimate $p_j = 1/3$. If plot 18 had been drawn instead of plot 10 to represent the specific group, the proportion of A_j would have been estimated to be zero.

In the initial photo-plot sample, every area A_i is considered as a stratum. If the photo plot were drawn randomly for each A_i, the variance under which every photo plot i is taken would be P_iQ_i. As proportional allocation of photo plots is applied (strata are of equal size), the population variance of proportion P is (cf. COCHRAN 1963, p. 107):

$$\sigma_{st}^2 \simeq \frac{1}{n} \sum_i^n W_i P_i Q_i = \sum_i^n P_i Q_i / n^2$$

where

P_i = proportion to be estimated in area A_i and $Q_i = 1 - P_i$

If random sampling had been applied in the location of photo sample plots over the total area, the coefficient g would have received the value one. Respectively, the variance of P would have been (cf. COCHRAN 1963, p. 50):

$$\sigma_r^2 \simeq PQ / n$$

On the basis of population parameters, g can be defined as:

$$g_{(pop)} = \sigma_{st}^2 / \sigma_r^2$$

In practice the variance PQ can be estimated by treating photo sample plots as if they were drawn randomly from the entire population. The estimation of σ^2_{st} can be based on the use of supplementary photo-plot sampling by areas A_i. On each selected area A_i, some number of additional plots, for instance 10, should be located and interpreted in the same way as for the initial photo sample plots. The coefficient is then (by direct application of the equation based on population parameters):

$$g = s_{st}^2 / s_r^2 \qquad (2234.7)$$

The variance estimator for means, such as for the mean volume of growing stock, is derived according to the principles described for area proportions. After constructing homogeneous group sets k', the variance estimator is obtained (cf. Equations 2234.1—2234.6 and COCHRAN 1963, p. 333) as follows:

$$v_{\bar{y}} = \frac{n}{n-1}\left\{\sum_{k'}^{m'} (w_{k'}^2 - \frac{w_{k'}}{n}) \frac{s_{k'}^2}{m_{k'}} + \frac{1}{n}\sum_{k'}^{m'} w_{k'}(\bar{y}_{k'} - \bar{y})^2\right\}$$

$$\simeq \sum_{k'}^{m'} w_{k'}^2 \frac{s_{k'}^2}{m_{k'}} + \frac{1}{n}\sum_{k'}^{m'} w_{k'} (\bar{y}_{k'} - \bar{y})^2 \qquad (2234.8)$$

This equation can be modified in the same way as Equation 2234.2, i.e.

$$v_{\bar{y}} = \frac{v_1}{m} + g\frac{v_2}{n} \qquad (2234.9)$$

where

$$v_1 = m \sum_{k'}^{m'} w_{k'}^2 \frac{s_{k'}^2}{m_{k'}} \qquad (2234.10)$$

= variance within groups, and

$$v_2 = \sum_{k'}^{m'} w_{k'}(\bar{y}_{k'} - \bar{\bar{y}})^2 \qquad (2234.11)$$

= variance between groups

g = correction coefficient resulting from the systematic location of photo sample plots. The coefficient can be estimated according to the principles underlying Equation 2234.7.

The estimation of $s_{k'}^2$ in Equation 2234.10 may run into difficulty in constructing homogenous group sets for quantitative charecteristics. This is true especially when a variance should be estimated, for example, for a mean volume of a specific subset, and the group sets should be homogeneous in respect of both the subset and volume. In order to avoid the necessity of making group sets homogeneous as regards the volume of the growing stock, the regression of y on x can be calculated and the estimation of $s_{k'}^2$ can be based on the deviations of y_i measured in the field from $\hat{y}_i$ obtained by regression estimator. Assuming the variance within groups equal by group sets and denoting it by $s_{y \cdot xk'}^2$, the variance v_1 obtained from Equation 2234.10:

$$v_1 = m \sum_{k'}^{m'} w_{k'}^2 \frac{s_{y \cdot xk'}^2}{m_{k'}} \qquad (2234.12)$$

where (cf. COCHRAN 1963, p. 202)

$$s_{y \cdot xk'}^2 = \frac{1}{m_{k'}-2}\left[\sum_{k=1}^{m_{k'}} (y_{k'k} - \bar{y}_{k'})^2 - b_{k'}^2 \sum_{k}^{m_{k'}} (x_{k'k} - \bar{x}_{k'})^2\right] \qquad (2234.13)$$

with

$b_{k'}$ = regression coefficient in group set k', when regression estimator is of form $y = a + bx$

Equations 2234.12 and 2234.13 are based on the assumption that the values x_i within any one group are equal. In other words, the groups are assumed to be homogeneous as regards the values x_i used as independent variable in the regression equation.

If the assumption of homogeneity of values x_i within the groups is not valid, the application of the above equations may lead to distinct under-estimation of the variances. This can be illustrated by a theoretical example. Three assumptions are made: (1) a good correlation exists between y and x, (2) no variance exists between groups in a group set k' and (3) no effort has been given to make the group homogeneous. Under these conditions, the estimator 2234.12 can lead to zero variance, whereas the true variance v_1 may equal the total variance s_y^2.

In the case that there is considerable heterogeneity in respect of x within separate groups, another estimator should be used instead of 2234.12. Variance within a specific group k can be written as (cf. COCHRAN 1963, pp. 339 and 336):

$$s_{yk}^2 = s_{y\cdot xk}^2 + r_k^2 \, s_{yk}^2$$

$$= s_{y\cdot xk}^2 + b_k^2 \, s_{xk}^2$$

where

s_{yk}^2 = variance of y within group k
$s_{y\cdot xk}^2$ = variance of y unexplained by a regression line within group k
r_k = coefficient of correlation between y and x
b_k = coefficient of regression of y on x
s_{xk}^2 = variance of x within group k

Assuming that $s_{y\cdot xk}^2 = s_{y\cdot xk'}^2$ and $b_k = b_{k'}$, the estimator of 2234.12 can be written as

$$v_1 = m \sum_{k'}^{m'} \frac{w_{k'}^2}{m_{k'}} \left(s_{y\cdot xk'}^2 + b_{k'}^2 \sum_{k}^{m_{k'}} s_{xk'k}^2 / m_{k'} \right) \qquad (2234.14)$$

where

$$s_{xk'k}^2 = \sum_{i}^{n_k} (x_{k'ki} - \bar{x}_{k'k})^2 / (n_k - 1)$$

In the above, three separate equations were given to estimate variances within groups for quantitative characteristics. Accordingly, three estimators are necessary to estimate the variances between groups.

If the construction of homogeneous group sets is also possible in respect of quantitative characteristics, estimator 2234.10 can be used for v_1 and, accordingly, estimator 2234.11 for v_2. If, as usual, regression should be applied, the variance between groups is obviously the variance explained by regression. When estimator 2234.12 is used for v_1, the variance between groups is estimated as

$$v_2 = \sum_k^m w_k (\hat{y}_k - \bar{y})^2 \qquad (2234.15)$$

where

$\hat{y}_k$ = the value of y esimated by regression

When estimator 2234.14 is applied for v_1, the variance between groups should be estimated as

$$v_2 = \sum_k^m w_k \left[(\hat{y}_k - \bar{y})^2 - b_k^2 s_{xk}^2 \right] \qquad (2234.16)$$

The correction coefficient g in Equation 2234.9 can be estimated according to the same principles as applied in connection with area proportions. The variances within squares, σ^2_{st}, and random variances, σ^2_r, should be estimated, and the coefficient is obtained as expressed in Equation 2234.7.

If proportional allocation of field sample plots is applied, the following equation is applicable:

$$v = v_1 + v_2 \qquad (2234.17)$$

where

v = total variance of characteristic to be estimated (s_y^2 for instance)
v_1 = variance within groups
v_2 = variance between groups

Even if the groups are approximately equal in size, Equation 2234.17 can be expected to be applicable (cf. COCHRAN 1963, pp. 119—120).

3. MATERIALS

31. **Field observations**

311. Location of field plots

The area from which material was collected is shown in Fig. 311.1. The choice was influenced by the need to select an area which was sufficiently varied for the purposes of the study, and which had recently been aerially photographed. A contributory factor in the selection was the fact that field

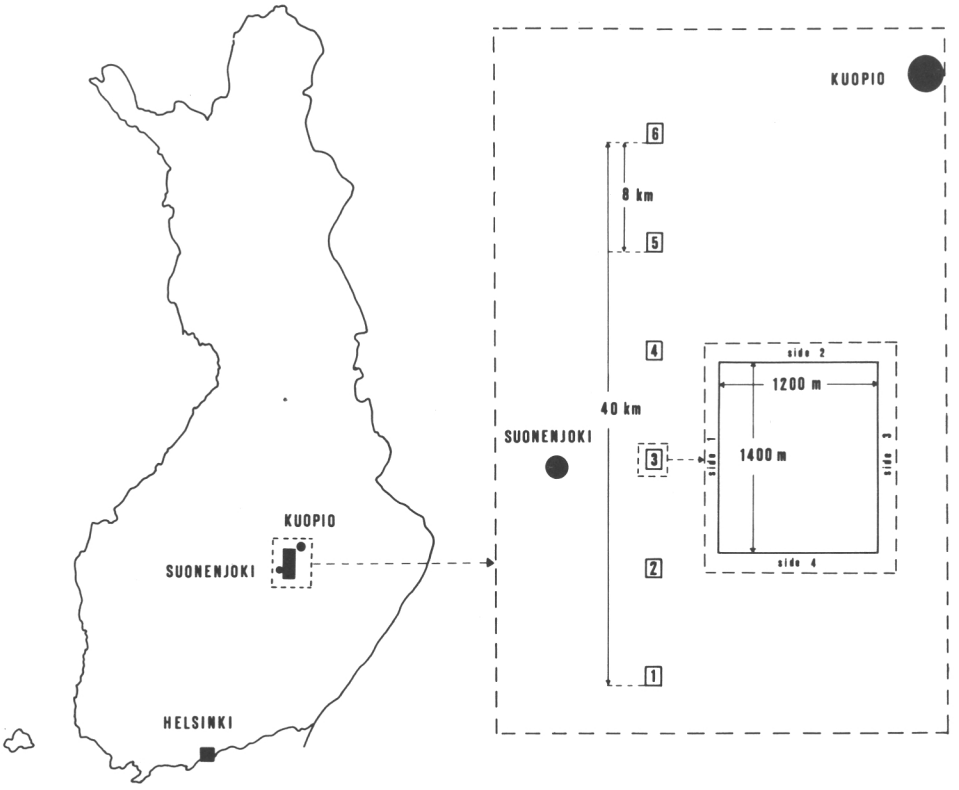


Fig. 311.1. The study area and the tracts
Kuva 311.1. Tutkimusalue ja lohkot

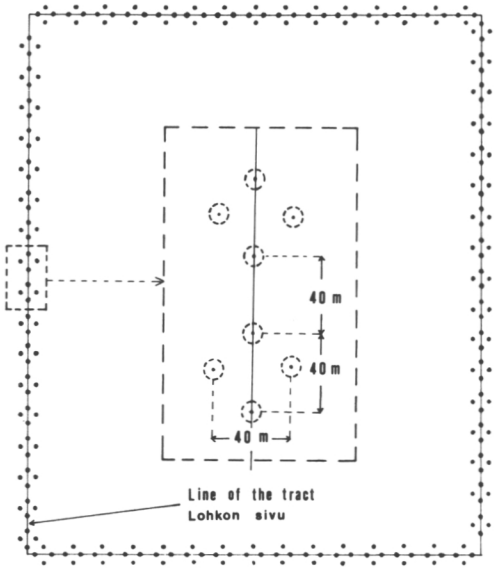


Fig. 311.2. Plots of Material 1967 belonging to one of the tracts
Kuva 311.2. Aineiston 1967 yhden lohkon koealat

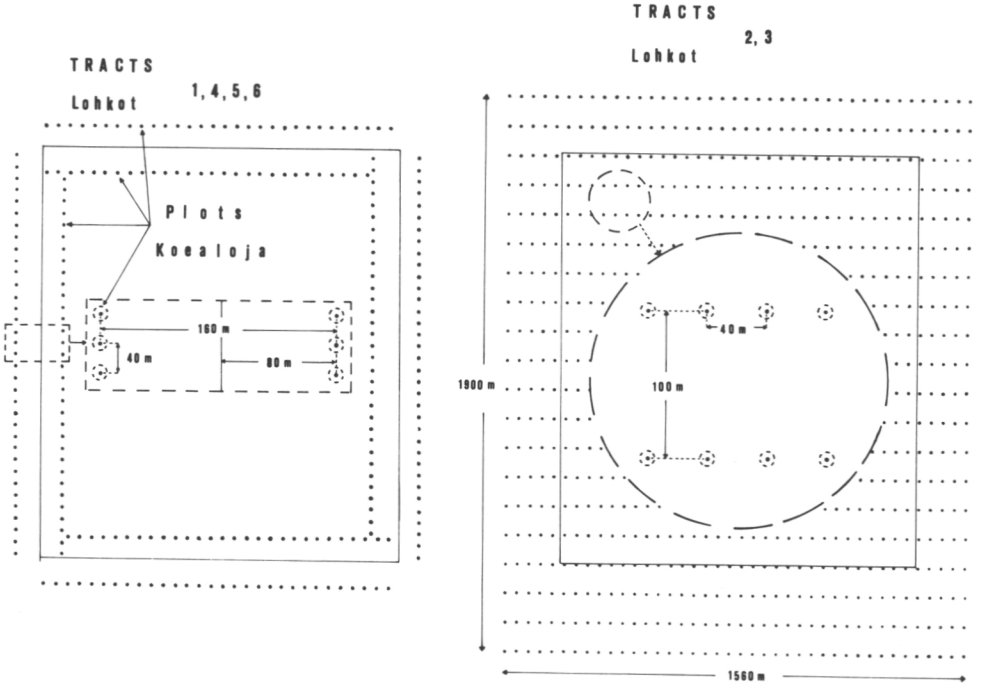


Fig. 311.3. Plots of Material 1968
Kuva 311.3. Aineiston 1968 koealat

work for the Fifth National Forest Inventory was being carried out in the area at about the time of the study.

The sample unit selected for collecting test material was a variable plot with a basal area factor of one (BAF = 1, each tallied tree representing 1 m² of basal area per hectare at breast height). This solution was adopted because the National Forest Inventory also used a variable plot, though with BAF = 2. The larger variable plot was chosen in the hope of achieving a better correlation between aerial-photo and field estimates.

The location of the sample units was based on the tract-wise sampling used in the Fifth National Forest Inventory. The tracts were rectangular, 1.2 x 1.4 km, at 8 - km intervals (Fig. 311.1). Measurements were made in the summers of 1967 and 1968. Two sets of material were collected, called Material 1967 and Material 1968. The former comprised 1 536 and the latter 2 612 sample plots (Figs. 311.2 and 311.3). The material was not collected expressly for the present study, but for optimization of sample units and for cartographic studies.

The location of the sample plots was identified on aerial photos by means of a transparent dot grid, which was either separate or photographed on the aerial photos. The position of the sample plot in the field was determined at

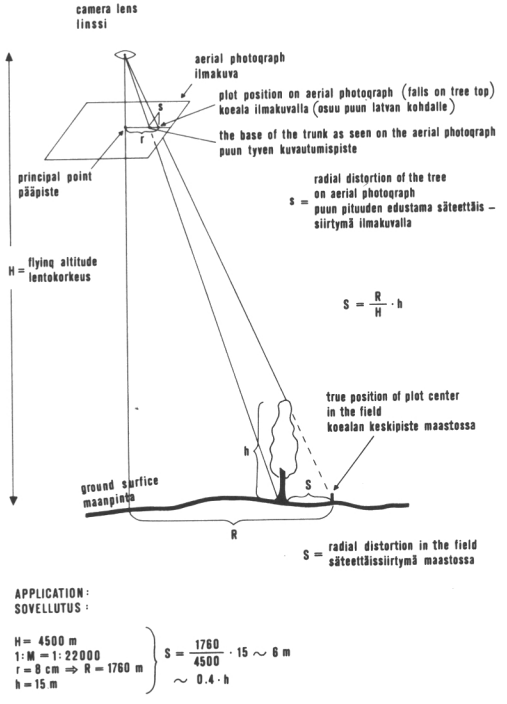


Fig. 311.4. Radial distortion in the field
Kuva 311.4. Säteettäissiirtymä maastossa

ground level according to the dot on the aerial photo. When positioning started from a tree crown visible on the photo, field distortion had to be taken into account (Fig. 311.4). This was estimated as a proportion of the height of the crown from ground level. The direction of distortion was determined by means of the aerial photo and a compass.

The error in locating the plot in the field was usually considered to be not more than 2 metres. After some training, it became possible to locate a plot in 1—10 minutes. Experience showed that reverse positioning of a plot from field to aerial photo would have been much more difficult.

In the Material 1967, the correspondence in the position of the plots on the photographs and in the field was not as good as expected from the precision of location of field plots. This was because the dots were placed on the photographs by separate transparent sheets in the Material 1967. In varying humidity and temperature, the photos contracted or expanded while the scale of the sheets stayed practically constant. This lack of correspondence between field and photo plots was eliminated in the Material 1968.

312. Field data; measurements and calculations

Field data was calculated for each plot by compartments. Calculations were based on a) tallying every tree belonging to the plot, b) selecting as

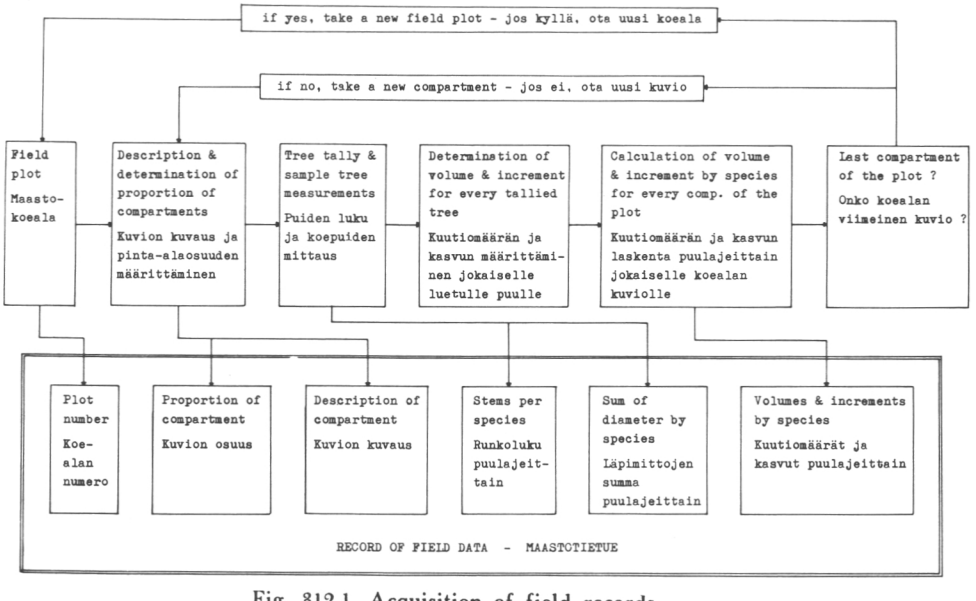


Fig. 312.1. Acquisition of field records
Kuva 312.1. Maastotietueiden hankinta

sample trees about 1/4 of all trees from each plot to be measured, c) deriving the estimators for volume and growth, and d) estimating the necessary characteristics for every compartment of the plot. The procedure of data collection and recording field data is shown in the box diagram in Fig. 312.1.

Compartments were delineated and classified according to the Fifth National Forest Inventory of Finland (see KUUSELA & SALMINEN 1969, pp. 16—17). This was done visually at or in the vicinity of the centre of the plot. Each plot necessitated the classification of at least one compartment. For example, in cases 3 and 4 in Fig. 312.2, three separate classifications had to be made. As shown in the figure, the sum of the area proportions of the compartments per plot ($p_{ia}+p_{ib}+\ldots$) always equalled 1.0.

On the variable plots, all trees with a minimum dbh of 4.5 cm were tallied by tree species, using a 1-cm classification. The trees were entered on field-tally sheets and punched on cards so that every tree could be placed in the right plot and compartment.

Both the breast-height diameters of standing trees and the stump diameters of trees felled after the photographs had been taken were measured in the field. Stump diameters were converted into breast-height diameters. Where the felled tree had grown inside the sample plot, it was entered on the

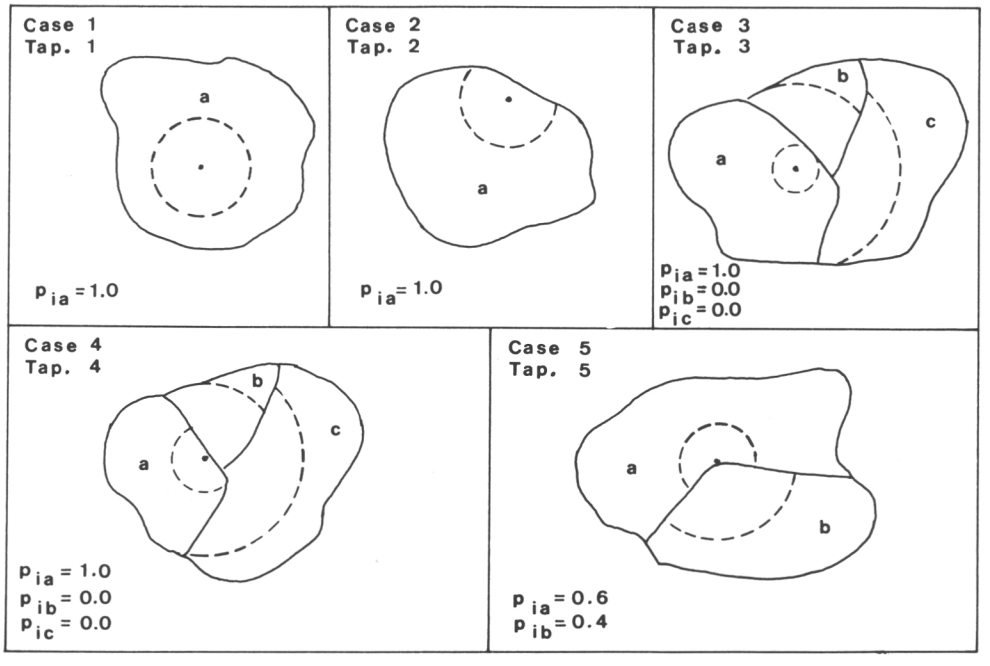


Fig. 312.2. Area proportion (p) of a compartment on a variable plot
Kuva 312.2. Kuvion pinta-alaosuus (p) relaskooppikoealalla

tally sheet as if it had been a standing tree. These trees were also treated in calculations as if they had not been felled. This was an attempt to eliminate the lack of correlation between data measured in the field and that interpreted from aerial photos taken at an earlier date.

To determine the unit volume and increment of the trees tallied from the field plots, every first, fifth, ninth (etc.) tree of every stocked plot of the Material 1967 was selected as a sample tree (total 2 732 trees). These trees were measured to enable use of ILVESSALO'S volume and growth tables for standing trees (1948): breast-height diameter (dbh) with 1-cm classification; height with 1-metre classification; diameter increment excluding bark, in mm, as the sum of radial increments during 5 years; height increment in dm, for coniferous species during the preceding 5 years; and the tree storey for deciduous species. Taper-class data for the sample trees were derived from the material of the Fifth National Forest Inventory in the test area and its surroundings. Only some 400 taper-class observations were obtained in this way.

Volume in cubic meters and percentage increment were taken from ILVESSALO'S tables (1948) for every sample tree. The sample trees were stratified into 19 sets according to tree species, site and treatment class. The volumes and increments of each sample tree were marked on an XY plane, on which the X axis referred to dbh and Y to volume or volume increment. The curves were drawn free-hand for all 19 sets and for volume and volume increment separately.

To calculate the volume and increment of each plot compartment, the values obtained from the curves were fed into the computer memory as tables, two tables for each set. In the computative procedure, the correct set and dbh were identified first for each tallied tree. It was then easy to find the volume and increment for every tree.

According to the variable-plot technique, each tallied tree represented the basal area of 1 m^2/ha (BITTERLICH 1948). Consequently, the form height (fh, see NYYSSÖNEN 1954, p. 19, or VU, see KUUSELA & SALMINEN 1969, p. 58) represented the volume of a tree in m^3/ha. When the fh values were supplied with subscripts i, t, r and s, indicating sample plot, compartment, tree species and individual tree respectively, the data unit of the volume used in further calculations was obtained as

$$V_{itr} = \sum_{s} fh_{itrs}$$

Based on these data units, the parameters required for tests could be calculated. For example, the volume of a variable plot i was calculated as

$$V_{i(m^3/ha)} = \sum_t \sum_r V_{itr}$$

Volume increment could also be calculated on the same principle as the volume. In the preceding formulas, the increment (indicated by I) could be substituted for volume (denoted by V).

The same kind of data units as those for volume and volume increment were calculated for tree numbers (M_{itr}) and for diameter sums (SD_{itr}). In this way, it became possible to calculate the mean diameters for any subclasses which could be formed from the compartments. All four kinds of data units, V_{itr}, I_{itr}, M_{itr} and SD_{itr}, were fed, together with the data describing the corresponding compartments, on to magnetic tape for further calculations (cf. Fig. 312.1).

32. Photo interpretations

All the photo plots visited in the field were interpreted from aerial photographs. In interpretation, the radial distortion had to be taken into account in the field (see Fig. 311.4). Thus, the position of field and photo plots corresponded exactly to each other. This was in accordance with the objective of photo interpretation: to ensure as high a correlation as possible between the data obtained in the field and that from aerial photographs.

The photo interpretations were made by two persons: a student of forestry and a Bachelor of Forestry, indicated respectively as *Interpreter a* and *Interpreter b. Interpreter a* worked in the immediate neighbourhood of the test area in the summers of 1967 and 1968 and interpreted both Material 1967 and Material 1968. Before starting, he collected 10 stereograms which he and *Interpreter b* were able to use for their photo estimations. Thus, *Interpreter a* had a good idea of the character of the forests of the area. *Interpreter b* did not visit the test area. He worked during the winter of 1967—68 and interpreted only the Material 1967.

The vertical photographs used in the tests (Fig. 32.1) were glossy contact copies, scale about 1: 22 000 and format 18 x 18 cm. The photographs were taken in summer 1966 at a flying altitude of about 4 500 metres on black-and-white panchromatic film by the National Board of Survey in Finland. Stereoscopic pairs were observed through a lens stereoscope with a magnification of 2.8. When necessary, ordinary focusing lamps were used in addition to or instead of sunlight.

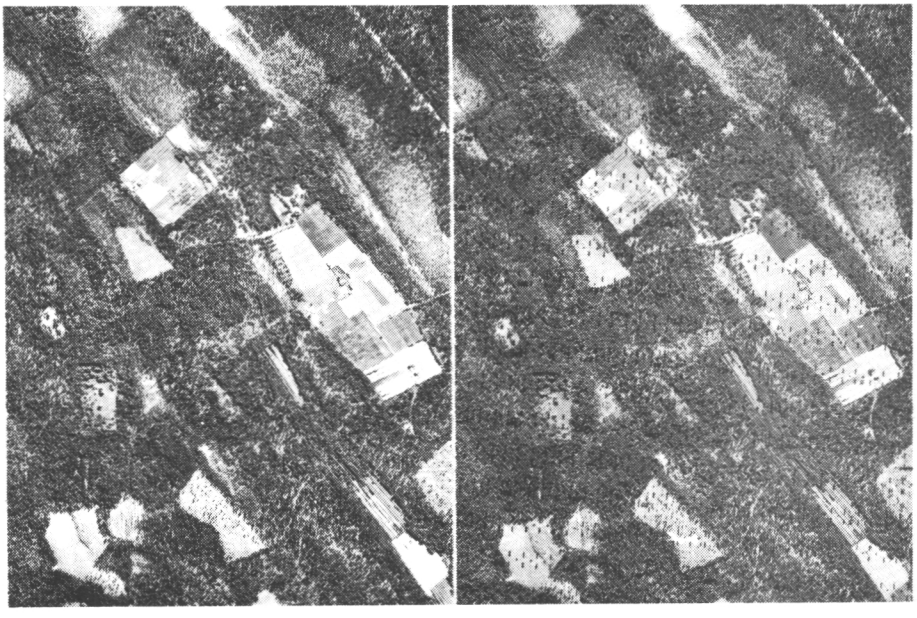


Fig. 32.1. A stereoscopic pair applied. Photographed by National Board of Survey
Kuva 32.1. Tutkimuksessa käytetty kuvapari. Maanmittaushallituksen kuvaus.

The interpretation of all characteristics of interest was not regarded as a practical possibility. Only those which were expected to attain sufficiently high correlation with important characteristics measured in the field were taken for photo interpretation. For good correlation, it was not felt necessary to have exactly the same grading system for estimating the characteristics from field and photo plots; in fact it was not even regarded as feasible because aiming at a good absolute correspondence would have required the thorough training of a photo interpreter in field classifications. Thus, the grading system applied was, in respect of some characteristics, on a relative basis (Table 32.1).

Some characteristics (land-use class, basal area, mean height) had the same grading both in the field and in the photo interpretations. Major differences were encountered in respect of site and treatment class. The characteristic »homogeneity» had no correspondence in the field.

In the relative grading, the range 1—9 was applied. Usually grade 1 meant the lowest, 5 average, and 9 the highest possible value of a characteristic. For example, the homogeneity of a very uneven stand with gaps in the growing stock was assessed at 1, moderately even at 5, and very even at 9.

The grading of treatment class was relative to stand rotation. The grades were defined as follows (cf. KUUSELA & SALMINEN 1969, pp. 27—28):

Table 32.1. Characteristics of forest-land compartments interpreted from air photos, and their grading.

Taulukko 32.1. Ilmakuvilta tulkitut metsämaan kuvioita koskevat tunnukset ja niiden luokitus.

Stand characteristic **Metsikkötunnus**	**Grading** **Luokitus**	
Basal area, m²/ha *Pohjapinta-ala,*	00 — 99	
Mean height, metres *Keskipituus,*	00 — 99	
Growing-stock volume, 10 m³/ha *Puuston kuutiomäärä,*	00 — 99	
Composition of tree species *Puulajisuhteet*	pine — *mänty* 0 — 9 spruce — *kuusi* 0 — 9 broad-leaved — *lehtip.* 0 — 9	Sum = 0 or 9 *Summa* = 0 *tai* 9
Homogeneity of stand *Metsikön homogeenisuus*	1 — 9	
Treatment class of stand *Metsikön kehitysaste*	1 — 9	
Nutrient content of soil *Maaperän ravinteisuus*	1 — 9	
Moisture content of soil *Maaperän kosteus*	1 — 9	
Stoniness of soil (only on mineral soils) *Maaperän kivisyys (vain kangasmailla)*	1 — 9	
Degree of soil drainage (only on swamps) *Maaperän kuivatusaste (vain soilla)*	1 — 9	

1 = seedling stand, the identification of which from a clear-cut or other open area is difficult by means of photo interpretation
2 = seedling and sapling stand, which differs distinctly from open areas
3 = young thinning stand
4 = older thinning stand
5 = regeneration within 20 years (preparatory stand)
6 = generation within 10 years (mature stand)
7 = regeneration within 5 years (shelter-wood stand)
8 = regeneration immediately (low-yielding stand)
9 = open area and seed-tree stand

Site type was interpreted by estimating three characteristics: nutrient content, moisture content and stoniness or degree of drainage. The following examples are presented concerning the determination of these characteristics:

nutrient content

1 = very poor site (rock or *Sphagnum fuscum* bog)
5 = damp site (average nutrient content)
9 = very rich site (grove)

LAND USE CLASSES

Maaluokat

PHOTO — Ilmakuva \ FIELD — Maasto	1	2	3	4	5	6	7	1-7
1	335	1	1	2	1	0	1	341
2	2	2	5	0	0	0	0	9
3	0	0	5	0	0	0	0	5
4	3	0	0	32	0	0	0	35
5	0	0	0	5	0	0	0	5
6	2	0	0	2	0	6	0	10
7	2	0	2	1	0	0	40	45
1-7	344	3	13	42	1	6	41	450

TREATMENT CLASSES

Kehitysluokat

PHOTO — Ilmakuva \ FIELD — Maasto	1	2	3	4	5	6	7	8	1-8
1	0	1	0	2	0	0	1	2	6
2	3	7	11	5	0	0	0	1	27
3	0	3	5	23	6	7	4	7	55
4	0	3	1	20	10	2	1	1	39
5	0	0	0	7	25	22	5	0	59
6	0	0	0	7	15	31	4	10	67
7	3	3	3	3	3	0	8	1	24
8	0	9	0	9	3	4	9	13	47
9	5	0	5	1	0	0	0	2	13
1-9	11	26	25	77	62	66	32	38	337

SITE FERTILITY CLASSES

Kasvupaikkaluokat

PHOTO — Ilmakuva \ FIELD — Maasto	2	3	4	5	2-5
3	0	0	2	11	13
4	1	21	44	12	78
5	13	52	40	5	114
6	34	61	11	1	107
7	27	17	0	0	44
3-7	75	155	97	29	356

PLOT VOLUMES

Koealojen kuutiot

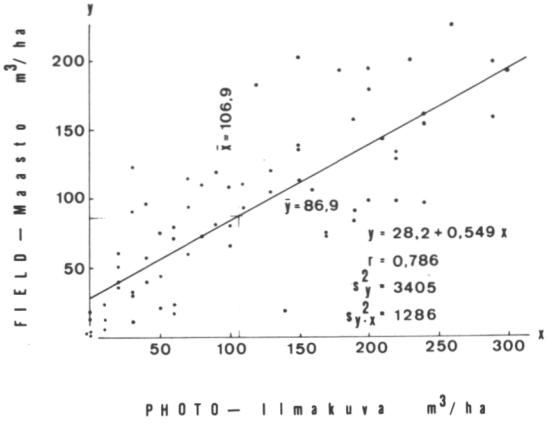


Fig. 32.2. Correlation between photo and field estimations
Kuva 32.2. Ilmakuva- ja maastoestimaattien välinen korrelaatio

moisture content
1 = rock
5 = optimum moisture
9 = watery swamp
stoniness (determined only if the site was interpreted as mineral soil)
1 = fine sedimentary soil
5 = average stoniness
9 = bare rock or sites with scattered boulders
degree of drainage (determined only if the site was interpreted as swamp)
1 = waterlogged, unditched swamp
5 = ditched swamp, moderate drainage
9 = transformed peat sites, good drainage

If the land-use class was interpreted as poorly productive forest land instead of normal forest land, interpretations were carried out according to the principles laid down in Table 32.1, except that the treatment class was not interpreted. For sites interpreted as waste land, only the last 4 characteristecs, indicating site quality, were estimated. For the remaining land-use classes, only the code corresponding to the interpreted land-use class was entered on the sheets.

The precision of photo interpretations varied naturally according to many factors, as shown in Fig. 122.1 (p. 10). The precision obtained in the tests is illustrated in Figure 32.2.

The unit for which the photo interpretations were made was a plot compartment. Thus, the units were defined on the same principles as in the field. In practice, however, it often happened that the division of a plot into compartments was not the same in the field as when interpreted from aerial photographs. Despite this, the photo-interpretation data records (Fig. 32.3) were obtained by a largely parallel scheme as the field data (cf. Fig. 312.1).

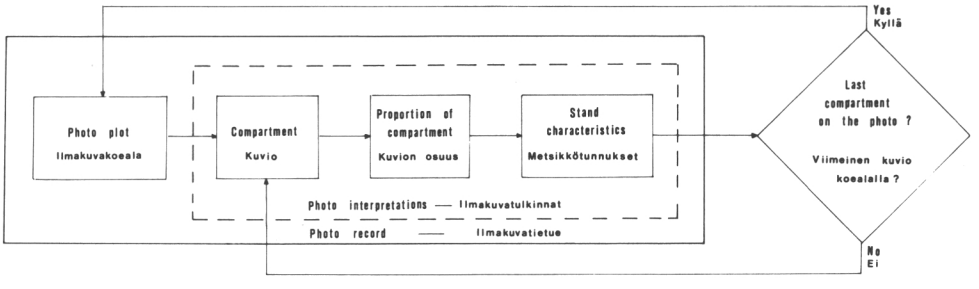


Fig. 32.3. Formation of photo records
Kuva 32.3. Ilmakuvatietueiden muodostuminen

In order to avoid the extra autocorrelation of photo interpretations between consecutive plots, those plots were not interpreted successively in the Material 1967. The field distance between successively interpreted plots was 80 metres instead of 20, and the plots consecutive in the field (Fig. 311.2) were interpreted at intervals of several days. In Material 1968 (see Fig. 311.3), however, the plots at 40-metre intervals along the lines were interpreted in consecutive order.

4. APPLICATION OF DIFFERENT METHODS

41. **Experiments on the grouping method**

411. Arrangement of test materials

The Material 1967 was estimated from aerial photographs by two interpreters *a* and *b*, the Material 1968 only by *Interpreter a.* All these 3 material / interpreter combinations were grouped by applying two group sizes. Accordingly, this procedure resulted in 6 material / interpreter / group size combinations. In Section 41, the term »Material» refers to one of these combinations if a special definition is not given. The derivation of materials is described in Fig. 411.1.

In the procedure described by Fig. 411.1, each combination represented a first-phase sample (photo sample) of the grouping method. Second-phase

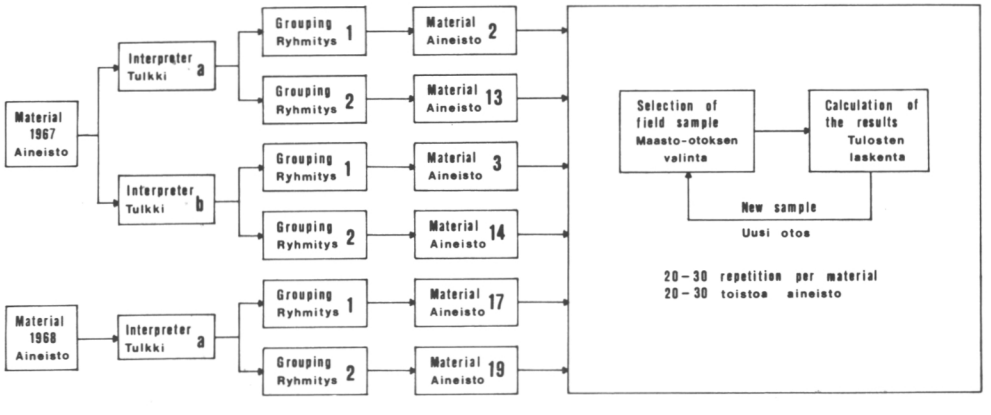


Fig. 411.1. Formation of test materials of the grouping method
Kuva 411.1. Ryhmitysmenetelmän testiaineistojen muodostaminen

(field) sampling was repeated 20—30 times for each material. The »first-hand» parameters such as proportions and volumes of various area classes were calculated for each sample repetition (see large box in Fig. 411.1). This repetition procedure made it possible to calculate the »second-hand» parameters, i.e. variances of proportions and means by simple variance formulas, and to compare them with those estimated by the grouping method applying the estimators of Chapter 2.

The grouping of the photo plots was carried out for all the materials with a punch-card sorter. For this purpose, the data from photo-interpretation sheets was transferred to punch cards. In this work, the photo estimations of different compartments of divided photo plots were placed together on one card. Thus one card presented the data from one photo plot. In five materials (in all but Material 14), sorting was based on photo estimations as such. First the photo plots were sorted into land-use classes. Then swamps and mineral soils were separated. Within forest land, the main emphasis was placed on volume and nutrient content, while tree species composition, treatment class, moisture content and stoniness, and degree of drainage, received less weight. The aim was to find as homogeneous groups as possible with regard to the most important photo estimations.

In the grouping of the photo plots of Material 14, the component results of factor analysis, factor scores, were utilized. Two factor scores were produced for each photo plot interpreted as forest land, using the library programme HYLPS at the Helsinki University Computer Centre. The scores represented the similarity of photo plots in two dimensional space. The scores with photo-plot numbers and original photo estimations were punched on cards. The grouping could now be based on the factor scores. This made the work easier and probably more reliable because the cards had to be sorted only on two factors. There were only a few cases in which ocular inspection of the groups revealed an obvious lack of homogeneity and the score-based grouping was changed.

An effort was made to produce equal-sized groups, especially within forest land. This made the allocation of the sample almost proportional (the probability of any photo plot being drawn into the field sample was about equal). Deviations from equality applied mainly to the most heterogeneous and most heavily stocked groups, which were a little smaller than the average.

Random selection of field plots from groups (one field plot per group) and the calculation of first-hand results were undertaken at the Helsinki University Computer Centre. Random numbers were generated using an automatic computer. An example of the calculations is given in an output list in Appendix 1 (pp. 124—125).

Some specifications for the materials are given in Table 411.1. This shows that the number of photo plots (first-phase sample) was 1 536 or 2 612, and

Table 411.1. Characteristics of the test materials of the grouping method
Taulukko 411.1. Ryhmitysmenetelmän testiaineistojen ominaisuuksia

Test Material *Testi-aineisto*	Inter-preter *Tulkki*	Total plots *Koealoja yhteensä*	Total groups *Ryhmiä yhteensä*	Groups on I+II* *Ryhmiä* I+II*	Repeated samples *Toisto-otoksia*
2	a	1536	78	65	20
3	b	1536	81	65	20
13	a	1536	152	131	20
14	b	1536	150	131	20
17	a	2612	90	71	30
19	a	2612	179	142	30

*) I+II refers to land-use classes normal and poorly productive forest land
*) I+II *viittaa maaluokkiin metsä- ja kitumaa*

that of field plots ranged from 78 to 179. The number of field plots (groups) which had been interpreted from aerial photographs as forest land (land-use class I) or poorly productive forest land (land-use class II) was fixed beforehand. This arrangement was aimed at improving the comparability within forest land of the results obtained by different materials.

412. Calculation of area proportions and means

In theory, an examination could have been made of all the area-class items included in the description of compartments, such as land-use class, land class (i.e. mineral soils, spruce swamps, pine swamps or open swamps), fertility class, treatment class, age class, as well as the diversity of combinations of items, such as treatment classes on mineral soils. The proportions of the following area classes were calculated (see Appendix 1, pp. 124—125): land-use class on total area and by land classes, fertility class on forest land and by land classes, treatment class, stoniness class and age class.

Mean volumes were calculated (see Appendix 1) by tree species for four area classes: forest land, poorly productive forest land, a combination of these two land-use classes, and total area (including all land-use classes). Mean volumes, without distinguishing tree species, were calculated for site-fertility classes on forest land and by land classes of forest land. In addition, the calculation of mean volumes, mean diameters and mean increments were accomplished by treatment classes. The calculation of means was based on the use of a ratio estimator, i.e. $\bar{y}_j = \sum_i y_{ji}/n_j$, in which y_{ji} = the measure of

plot i belonging to area class j, and n_j = the number of plots belonging to area class j. In practice, n_j can be considered the sum of plot compartments (cf. Fig. 312.2, p. 41) belonging to subset j.

Some of the calculations are presented, by materials, in Appendix 2 (pp. 126—127). The area proportions and means of the materials were calculated according to all repetitions of the respective material. The variances were derived simply from the results of the repetitions as described in Section 411.

413. Calculation of variances

In the description of the grouping method, it was assumed that photo plots were located equidistantly over the whole area undergoing the inventory. However, the location of plots in the test materials was far from that recommended, as Figures 311.1, 311.2 and 311.3 show. This discrepancy was not considered to be particularly harmful in the test conditions because there was no need to connect the study with a specific population. In the relevant case the population was, in fact, considered to correspond to that which would have resulted in the test materials described above (see Fig. 411.1) if the equidistant location of photo plots had been applied.

The characteristics for which the variance estimators were tested were: area of forest land, area of mineral soils, areas of site-fertility classes, areas of treatment classes, mean volumes on total area, mean volume on forest land, mean volumes on site-fertility classes, mean volumes on treatment classes, mean volume of pine on forest land, mean volume of spruce on forest land and mean volume of broad-leaved species on forest land.

The tests were restricted to concern only variances within groups, v_1. This was because the variance within groups was considered the main source of the sampling variance as the number of field sample plots is usually much smaller than that of photo sample plots (see Equations 2234.6 and 2234.9). Another reason to the restriction was that a fairly good estimate for variance between groups can easily be derived on the basis of variance within groups, v_1 and total variance, v. Accordingly, $v_2 \sim v\text{-}v_1$. Neither was the coefficient g (Equation 2234.7) studied separately. The necessary estimates for it were obtained when systematic and random sampling were compared in Section 53.

Variances within groups were estimated according to Equations 2234.4 and 2234.12. Only variances of mean volumes (m^3/ha) for separate tree species were estimated according to Equation 2234.14. This was because there was substantial heterogeneity within groups in respect of tree species as interpreted from aerial photographs.

The greatest theoretical difficulties were associated with the variance

estimation for mean volumes on an area class which is not known but which has to be estimated. Even if the groups were homogeneous in respect of the area class as estimated on the photos, they could be heterogeneous in relation to field observations. The problem is introduced in Fig. 413.1.

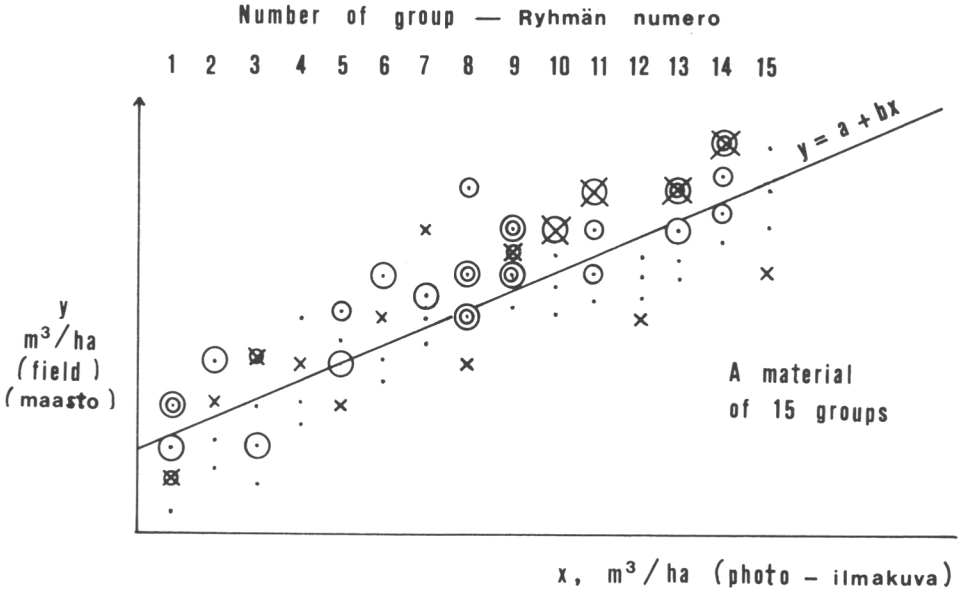


Fig. 413.1. Composition of the mean-volume variance in an area class (e.g. site -fertility class). A theoretical example.
Kuva 413.1. Pinta-alaluokan (esim. kasvupaikkaluokan) keskikuution varianssin muodostuminen. Teoreettinen esimerkki.

The figure is subject to the following assumptions:
— the field volumes corresponding to all photo plots are known (variable to be explained = y)
— the photo plots of any one group are homogeneous concerning the volume interpreted from aerial photos (explaining variable = x)
— the plots surrounded with a small circle are interpreted as belonging to the area class studied
— the plots surrounded with the large circle belong, according to field classification, to the area class studied
— the plots marked with a cross have been drawn by random sampling to represent their groups in field estimation (one of every four sample plots).

According to the grouping method, the mean volume on area class j is the mean of the field measurements in groups 10, 11, 13 and 14. For two reasons, the mean in the Figure is a gross over-estimate: (1) the field plots of area

class j (points with the large circle and cross) lie above the regression line, and (2) the x values corresponding to the above-mentioned field plots are much greater than the mean of the x values of all points with the large circle. Reason (2) shows that the uncertainty in area-class estimation from aerial photographs has a large effect on the variance of the mean of the area class. To include this variance source into the variance estimator in a statistically correct form is a complex procedure. In later estimates, this source is usually excluded and the resulting discrepancy can be seen conclusively in later comparative tabulations.

The variances were not estimated for all of the 140 samples (see Fig. 411.1 and Table 411.1) drawn from the six materials. This was because the calculation of a variance for a single sample was rather laborious and because the results proved to remain fairly stable from one sample to another. Consequently, the estimations from very many samples were not regarded as necessary.

414. Testing of variance estimators

4141. Variances based on repetitions

Usually there exists only one sample on which the variances have to be estimated. These types of variances are termed here *variances based on single samples.* Their estimation has been discussed in Sections 223 and 413. For testing purposes, samples have been drawn with repetitions. The variances calculated on the basis of estimates from repeated samples are called here *variances based on repetitions.* As the latter variances are more or less unbiased, their comparison with the respective variances based on single samples gives good material for making conclusions as to the grouping method in respect of variance estimation.

The variances based on repetitions were first calculated for each of the six materials (Fig. 411.1) separately. The results are recorded in Appendix 2 (pp. 126—127). A remarkable inconsistency can be noticed in the variances of different materials. This was caused by the fact that the number of repetitions (20 or 30) was small. Because of this inconsistency it was decided to combine all the repeated samples to achieve pooled variances which could be applied for comparisons. This procedure, of course, was based on the assumption that the true variances of the separate materials were about the same. As a result of the pooling procedure, the number of repetitions concerning each of the six materials (cf. Fig. 411.1) rose to 140.

The mathematics underlying the techniques referred to above is explained

by statistical formulas without any deep consideration of the arguments or derivations. Taking a measure of a plot, e.g. y = volume/ha, and denoting the material with subscript h, the variance of y of material h is:

$$v_{yh} = m_h v_{\bar{y}h}$$

where

v_{yh} = »population» variance of volume in material h
m_h = number of field plots in material h
$v_{\bar{y}h}$ = sample variance (variance of the mean volume) of material h based on repetitions.

The pooled variance of y over the six materials was calculated as:

$$v_y = \sum_{h=1}^{6} v_{yh} \; / \; 6$$

Finally, the variance to be applied in comparisons with those based on single samples was calculated for an individual material as

$$v'_{\bar{y}h} = v_y \; / \; m_h \qquad (4141.1)$$

Plot numbers m_h were determined according to the characteristic in question. As an example, for land-use class proportions and the mean volume on the total area, m_h comprised all the field-sample plots. For the mean volume on forest land, and the internal characteristics of forest land, only plots interpreted from aerial photographs as normal or poorly productive forest land were counted (Table 4141.1). Materials of the table connected with random sampling will be described later.

Some remarks should be made concerning the use of pooled variances derived according to Equation 4141.1. The applied pooling procedure means that only the sample size of the material affects the respective variance based on repetitions. In reality, the variances and their mutual relationships are also affected by the quality of the population, photo interpretation, grouping and group sets. If these factors could be assumed to be equal, the procedure was correct. If this assumption was not right, the resulting variances had to be regarded as too high for some materials and too low for others.

Table 4141.1. Number of field plots applied to the calculation of variances
Taulukko 4141.1. Varianssien laskennassa käytetyt maastokoealojen lukumäärät

Material *Aineisto*	Area class to be studied *Tutkittava pinta-alaluokka*		
	Total area *Koko alue*	Normal or poorly productive forest land as interpreted on photos *Ilmakuvatulkinnan mukaan metsä- tai kitumaata*	Forest land *Metsämaata*
h	m_h		
2	78	65	62.5
3	81	65	62.5
4	88	65	62.5
13	152	131	126.0
14	150	131	126.0
15	177	131	126.0
17	90	71	69.3
18	88	71	69.3
19	179	142	138.6
20	175	142	138.6

4142. Variances of the area classes

The variances based on single samples and those based on repetitions were recorded in Table 4142.1. In addition, to obtain some idea of the level of the variances in relation to those obtained by a more familiar method, the variances based on simple random sampling were included in the table.

To illustrate the procedures applied to the calculations in Table 4142.1, examples are given for the area class forest land. The 90 field plots of a sample from Material 17 were sorted into five group sets according to photo interpretations as follows:

Group set	Definition (based on photo interpretation)
1	Land-use class = 1, $m^3/ha \leqq 20$
2	» = 1, $m^3/ha > 20$
3	» = 2
4	» = 3—6
5	» = 7

The proportions of and the variances within group sets were calculated for each sample. For the first of the 10 samples investigated, the following set-up with enclosed variance was derived:

Group set k'	Proportion $w_{k'}$	p* (%)	p x q (%)
1	.156	100.0	0000
2	.599	99.1	0089
3	.023	50.0	2500
4	.122	9.1	0827
5	.100	0.0	0000
	1.000		

* proportion of forest land as measured in the field

$$\sum_{k'} w_{k'} p_{k'} q_{k'} = 212$$

Assuming proportional allocation of field sample plots

$$\frac{v_1}{m} = \frac{\sum_{k'} w_{k'} p_{k'} q_{k'}}{m} = \frac{212}{90} = 2.36\ \%$$

The mean of v_1/m of ten samples was 3.84 (Column 5 in Table 4142.1). The standard deviation of the 10 v_1/m-values was 1.37 percentage units. This was also recorded in the Table in order to give an idea of the level of consistency of the variance estimate obtained by the grouping method. The procedure in respect of calculating and recording the respective characteristics of other area classes was identical.

The variances based on single samples (Column 5) prove to be somewhat larger than those based on repetitions (Column 7). The differences cannot be regarded as significant, as can be easily concluded on the basis of the standard errors in Column 5. (The small standard error, 0.45, of the site-fertility classes may be considered coincidental.) Comparison of Columns 6 and 8 showed that the random sampling variances based on single samples, were somewhat larger than those based on repetitions. This is fairly well explained by the fact that the population (the set of photo plots) to which the repetition procedure was applied was rather small and that the finite population correction, N/ (N-n), about 1.04, was neglected for Column 8.

Table 4142.1. Testing of the grouping method with regard to variance estimators for proportions of different area classes
Taulukko 4142.1. Ryhmitysmenetelmän pinta-alaluokkien osuuksia koskevien varianssiestimaattorien testaus

Area class ***Pinta-alaluokka***	Single samples *Yksittäiset otokset*					Repeated samples *Toisto-otokset*			
	No. of samples tested *Tutkittuja otoksia*	No. of group sets *Ryhmäyhdistelmiä*	No. of field plots in a sample *Maastokoealojen luku otoksessa*	Grouping method *Ryhmitysmenetelmä*	Random sampling *Satunn. otanta*	Grouping method *Ryhmitysmenetelmä*	Random sampling *Satunn. otanta*	Grouping method *Ryhmitysmenetelmä*	Random sampling *Satunn. otanta*
				v_1/m, %	v/m, %	v_1/m, %	v/m, %	No. of repetitions *Toistoja, kpl*	
1	2	3	4	5	6	7	8	9	10
Forest land *Metsämaa*	10[1])	5	90	3.84 ± t · 1.37	19.55	3.34	15.73	140	70
Mineral soils *Kangasmaat*	10	6	90	9.61 ± t · 2.53	27.58	7.30	29.37	140	70
Site-fertility classes[2]) *Kasvupaikkaluokat[2])*	5[1])	3	69	29.45 ± t · 0.45	29.76	25.23	26.91	140	70
Treatment classes[3]) *Kehitysluokat[3])*	5	4	67	16.70 ± t · 0.96	19.51	16.11	15.52	140	70

[1]) The samples were selected randomly from Material 17
[1]) *Tutkittavat otokset valittiin satunnaisotannalla aineistosta 17*

[2]) Variances are averages of 4 classes
[2]) *Varianssit ovat 4 luokan keskiarvoja*

[3]) Variances are averages of 8 classes
[3]) *Varanssit ovat 8 luokan keskiarvoja*

The tests did not produce any proof against the utility of the grouping method for estimating the variances of area-class proportions. However, it can be concluded theoretically that lack of skill in constructing the group sets tends to lead to too high variance estimates.

4143. Variances of the mean volumes

The variances of volume within groups, v_1, were calculated first for four area classes and then for tree species on the area class forest land. The results are presented in Table 4143.1. Special attention was given to the variance of mean volume on forest land in relation to the problem concerning the volume variances of area classes which were not known but subject to estimation (see Section 413 and Fig. 413.1). It should be noticed that in Table 4143.1 the variance estimates are not in the form of »sampling variance» as in Table 4142.1. As the numbers of sampling units falling in different area classes varied, sampling variances of mean volumes were based on different

Table 4143.1. Grouping method with regard to the estimation of variances of mean volumes
Taulukko 4143.1 Ryhmitysmenetelmä keskikuutioiden varianssien estimoinnissa

Area class or tree species *Pinta-alaluokka tai puulaji*	Based on single samples *Yksittäisten otosten perusteella*			Based on repeated samples *Toisto-otosten perusteella*		
	Materials *Aineistot*	No. of samples *Otoksia kpl*	v_1	Materials *Aineistot*	No. of repetitions *Toisto-otoksia kpl*	v_1
1	2	3	4	5	6	7
Total area *Koko alue*	2, 3, 13, 14, 17, 19	30	741	2, 3, 13, 14, 17, 19	140	720
Forest land *Metsämaa*	»	30	1355	»	»	2013
Site-fertility classes *Kasvupaikkaluokat*	17	5	1015	»	»	2403
Treatment classes *Kehitysluokat*	17	5	1079	»	»	1997
Pine on forest land *Mänty metsämaalla*	17	5	858	»	»	1241
Spruce on forest land *Kuusi metsämaalla*	17	5	1513	»	»	1316
Broad-leaved on forest land *Lehtip. metsämaalla*	17	5	500	»	»	485

sample sizes, m, and therefore the presentation of variances in the form of v_1 was preferred to that of v_1/m.

The variances based on single samples were calculated for all volumes except those by tree species, on the assumption that the groups were homogeneous as far as the independent characteristic applied to Estimator 2234.12 (p. 34), photo-interpreted volume, was concerned. This assumption did not, of course, hold completely. It was not possible to construct all the groups to be homogeneous entirely in respect of all the photo-interpreted characteristics. The most weight in the grouping was given to land-use class and volume. Less weight was allocated to site-fertility and treatment class and tree species. The heterogeneity in the site-fertility and treatment classes existing in the materials was not considered to have any great influence on the variances because consecutive classes are easily confused with each other even in the field and the correlation between the photo and field estimations is not very high (see Fig. 32.2, p. 46). The case was different with mean volumes by tree species. Consequently, Equation 2234.14 was applied to tree species instead of Equation 2234.12.

On comparison of the variances of mean volumes (Columns 4 and 7 in Table 4143.1), it can be seen that the coincidence of the corresponding figures in the first row, variances of mean volume on total area (741 and 720), was good, those by tree species on forest land somewhat poorer, while on other classes (forest land, site-fertility and treatment classes) the estimator applied (Equation 2234.12) produced serious under-estimates (the figures in Column 4 were remarkably smaller than those in Column 7). This means that the true variance of mean volume increased rapidly when the precision in area-class interpretation decreased (cf. Fig. 413.1).

The effect of errors in area-class interpretation was especially detrimental, as mean volumes were estimated for small area classes such as site fertility and treatment. In fact, application of variance estimators based on random-sampling formulas instead of those of the grouping method produced fairly good variance estimates for mean volumes of small area classes, which will be discussed in later sections. In Table 4143.1, the variance of treatment classes based on single samples was 46 % smaller than that based on repetitions. If random-sampling formulas had been applied to the single samples, the variance would have exceeded by 14 % that based on repetitions. The situation was almost the same in respect of site-fertility classes.

In comparing the volume variances by tree species, some special features should be emphasized. The distribution of plot volumes of a tree species was relatively extreme (many zero and large values). The correlation of the plot volumes interpreted on aerial photos and measured in the field was distinctly less than that between photo and field volumes of all tree species. Finally, the variances of photo-interpreted volumes of a tree species within groups

were relatively large. Because of this, Equation 2234.14 instead of 2234.12 was applied to the estimation of variances. By this application, the variances of Columns 4 and 7 in the three last rows of Table 4143.1 came, on average, fairly close to each other. If Equation 2234.12 had been applied as in the case of other variance estimates based on single samples, the variances would have been about 21 % smaller and consequently considerable under-estimates would have resulted.

The application of the equations of the grouping method given above in Chapter 2 (Equations 2234.12 and 2234.14) for variance estimation seemed to work well as long as the area class was known, i.e. for total area. For small area classes, which were not interpreted with absolute precision from aerial photographs, the equations proved to be of less value. As the area of forest land was interpreted with relatively good precision (see Fig. 32.2) and as the mean volume on forest land was, as usual, considered an important parameter, more emphasis was given to the analysis concerning the estimation of variance of mean volume on forest land. For this purpose, Table 4143.2 was drawn up.

The table was based on the six test materials (6 rows). The variance was calculated for two assumptions: that the area of forest land was known, and that the area of forest land was not known. The calculations were made based both on single samples and on repetitions.

Column 4 of Table 4143.2 represents the »true» variance within the groups (calculated on the basis of all field plots on forest land) divided by m (the number of field sample plots on forest land). The estimates of the corresponding parameters based on the estimator of the grouping method (Equation 2234.12, p. 34) are given in Column 5. This contains the untenable assumption that the area of forest land was known exactly, in the same way as in the smaller area classes in Table 4143.1, Column 4.

Comparison of Columns 4 and 5 of Table 4143.2 shows that the grouping method consistently gave exaggerated estimates for variances within groups. The difference is about 16 % of the true variance. One of the causative factors was that one regression line did not explain completely the dependence of field-measured volume on that interpreted from aerial photographs (cf. Fig. 32.2). The probably more important effect was caused as the groups of a group set were not equally subject to systematic errors in photo interpretation. Systematic errors by groups do not affect the true V_1. The variation of systematic errors between groups of a group set leads toward over-estimates in v_1.

It was clear, from observing the single samples, that if the estimate of the proportion of forest land was too high the mean volume on forest land was usually too low; or *vice versa,* if the proportion of forest land was underestimated the mean volume was usually too high. The reason was that errors in interpretation of forest land concerned only open and sparsely stocked areas. By calculating the mean by equation $\bar{y}_j = \sum_i^n y_{ji} / n_j$ (see Section 412

Table 4143.2. Variance estimates of mean volume on forest land obtained by the grouping method
Taulukko 4143.2. Ryhmitysmenetelmällä saatuja metsämaan keskikuution varianssiestimaatteja

Material *Aineisto*	Mean volume on forest land *Metsämaan keskikuutio*	No. of samples investigated **Tutkittujen otosten lukumäärä**	True variance within groups divided by m **Todell. ryhm. sis. var. jaettuna m:llä** V_1/m	Estimates based on single samples with presupposition that the area of forest land is *Estimoinnin lähtökohtana yksittäiset otokset olettaen, että metsämaan pinta-ala on* — Known — *Tunnettu* — v_1/m — Mean *Keski-arvo*	v_1/m — Stand. error *Hajonta*	$v_1/m+v_2/n$ — Mean *Keski-arvo*	$v_1/m+v_2/n$ — Stand. error *Hajonta*	Not known *Ei tunnettu* — $(v_p/p)^2\bar{y}^2+v_{\bar{y}}$ — Mean *Keski-arvo*	$(v_p/p)^2\bar{y}^2+v_{\bar{y}}$ — Stand. error *Hajonta*	No. of repetitions *Toistojen lukumäärä*	Repeated samples — *Toisto-otokset* — The area of forest land is assumed to be *Olettamuksella, että metsämaan alue on* — Known *Tunnettu* — $v_{\bar{y}}$	Not known *Ei tunnettu* — $v_{\bar{y}}$,	Not known *Ei tunnettu* — $(v_p/p^2)\bar{y}^2+v_{\bar{y}}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	93.7	3	..	17.1	2.39	19.2	2.24	24.6	4.03	20	15.6	31.1	18.5
3	»	3	18.3	24.0	3.68	25.5	3.80	33.3	0.90	»	27.7	31.1	35.0
13	»	1	7.9	10.7	—	12.2	—	14.1	—	»	14.6	15.4	17.9
14	»	3	9.0	10.1	1.39	11.7	1.53	15.6	3.60	»	10.5	15.4	15.2
17	99.2	10	17.7	18.8	5.23	20.1	5.19	25.3	6.12	30	11.2	28.1	17.4
19	»	10	8.2	10.0	1.21	11.3	1.25	11.9	1.03	»	8.3	14.0	10.7

Notations of the Table

Column of Table			Meaning of symbols
4	V_1	=	$\sum_k^m W_k S_k^2$; W_k = proportion of group k; S_k^2 = variance of the field plot volumes interpreted from aerial photographs as forest land and belonging to group k
4	m	=	number of field plots on forest land
5, 6	v_1	=	variance of field-plot volumes around regression line ($s_{y_{ix}}^2$,all m field plots were in one group set)
5, 7, 9, 6, 8, 10	Mean	=	arithmetic mean of the variances of different samples
	Stand. err.	=	standard errors of variance estimates of different samples
7	v_2	=	variance between groups (= total variance minus variance within groups because the number of group sets was 1)
7	n	=	number of photo plots in m groups
9	v_p	=	variance estimate of forest-land proportion without the effect of v_2 (cf. Eq. 2234.6)
9	p	=	estimate of forest-land proportion in sample
9	$\bar{y}$	=	estimate of mean volume on forest land
9	$v_{\bar{y}}$	=	variance estimate of mean volume on forest land without the effect of v_2 (cf. Eq. 2234.9)
12	$v_{\bar{y}}$	=	variance estimate of the mean volume on forest land free from the effect of errors in proportion of forest land (The mean volume of a sample has been calculated by multiplying the mean volume of total area by the inverse value of the true proportion of forest land, i.e. by 1/P)
13	$v_{\bar{y}}$,	=	variance of mean volumes abtained by Equation 4143.1
14	v_p, p, $v_{\bar{y}}$	=	same as in Column 9 except that the parameters have been based on repeated samples

and Fig. 413.1, p. 52), the divider was subject to variation affecting the behavior of the errors referred to above.

The unbiased variances based on repetitions (Column 13 in Table 4143.2) were transformed to correspond to the variances presented in Column 5 (based on single samples, the area of forest land assumed to be known). The sample mean of each repetition was corrected to represent the true forest-land area by coefficient p/P, where p was the proportion of forest land on a sample and P the true proportion of forest land. The corrected mean volumes were treated as observations in calculating the variances, which were then recorded in Column 12. Comparison of Columns 5 and 12 shows that the transformation brought the variances approximately to the same level. That is in accordance with the above assumption: the discrepancy between the variances based on a single sample (Column 5) and those based on repetitions (Column 13) are mainly caused by errors in discerning forest and non-forest land by aerial-photo interpretation.

The preceding verification raises the question of how the variance estimator based on a single sample (Equation 2234.12) could be developed to produce less biased estimates, i.e. variances which were closer to those in Column 13 of Table 4143.2. This means that the errors in the estimation of an area class (forest land) should be included in the estimator. An attempt at a solution restricted to the area class forest land is described in the following paragraphs.

It was assumed that errors in interpreting plots in respect of whether they were forest land or not were made only on those plots with a volume of zero. The mean volumes of forest land obtained by the grouping method could on that basis be presented as:

$$\bar{y}' = (P/p)\bar{y} \qquad (4143.1)$$

where

$\bar{y}'$ = estimate of mean volume of forest land when both sample-plot volumes and proportion of forest land were subject to errors
P = the true proportion of forest land
p = estimated proportion of forest land obtained by the grouping method
$\bar{y}$ = estimate of mean volume of forest land when the area of forest land was assumed to be known

The estimate of variance of $\bar{y}'$ can be expressed according to SCHUMACHER & CHAPMAN (1942, p. 112), with the following simplified equation:

$$v_{\bar{y}'} = v_{(P/p)}\,\bar{y}^2 + v_{\bar{y}}\,(P/p)^2 \qquad (4143.2)$$

Based on the expectation that, in repetitions, P/p fluctuates evenly around 1, the equation was transformed to:

$$v_{\bar{y}'} = v_{(p/P)}\,\bar{y}^2 + v_{\bar{y}}\,(P/p)^2$$

$$= (v_p/P^2)\,\bar{y}^2 + v_{\bar{y}}\,(P/p)^2$$

and by substituting p for P, to:

$$v_{\bar{y}'} = (v_p/p^2)\,\bar{y}^2 + v_{\bar{y}} \qquad (4143.3)$$

All the terms of Equation 4143.3 can be obtained on the basis of a single sample. The application of the equation resulted in Column 9 (Table 4143.2). Comparing its figures with those of Column 5 shows that the new equation led to variance estimates which were approximately 37 % higher. The difference can be interpreted as representing the part produced by the errors made in interpreting the area class forest land. Comparison of variances based on Equation 4143.3 (Column 9) with those based on repetitions (Column 13) seems to show that the assumptions made for the equation, though they were not exactly correct, helped to produce a fairly good estimator of the variance of mean volume on forest land in the relevant case.

The consistency of the variances based on single samples can be examined with the figures of Columns 6, 8 and 10, which present the standard error of the separate variance estimates. A detail of interest may be that the consistency of variance increases very rapidly as sample size grows. This accords with theory (cf. SPIEGEL 1961, p. 144), and can be experienced by comparing the figures of Material 19 with those of Material 17 (the sample size in the former is twice that of the latter).

42. Calculations based on double sampling for stratification

The method of double sampling for stratification has been described in Sections 124 and 13 and in Figure 21.1. For comparative purposes, the most important factor to be experimented with was considered the variance within strata (cf. variance within groups in connection with the grouping method). Consequently, in planning the experiments, special attention was given to the strata sizes in which the photo plots were to be stratified.

Two kinds of stratification were applied. One, termed *Strat. a,* provided 13 field plots per stratum. In the other, termed *Strat. b,* strata were much

smaller and from each only two field plots were selected. The respective test materials consisted of the plots in Material 1968 (Fig. 411.1), as estimated by *Interpreter a.* The total number of photo-interpreted plots was 2612 in this material.

Usually, in double sampling for stratification, the plots are interpreted directly to prefixed strata. In tests the strata were determined after photo interpretation on their basis. Under method *Strat. a,* the sample plots interpreted from aerial photos as forest land were divided into 10 strata, each covering about 180 plots. Furthermore, as land-use classes II, III, IV, V + VI, and VII each formed a stratum, the total number of strata in method *Strat. a* was raised to 15. The field plots were selected for each stratum by proportional allocation without replacement, so that it produced 142 field plots from the 11 strata interpreted as normal or poorly productive forest land. The total of all field plots was 174. Thus, *Strat. a* corresponded to test Material 19 in Fig. 411.1 as to the field-sample size. This special material and its arrangement is termed Material 20. Field samples were selected 20 times. Each repetition was treated separately, as were those of the grouping method, and the results are presented in Appendix 2 (pp. 126—127). A general view of the correspondence and quality of method *Strat. a* and other methods in respect of the grouping method is given in Table 42.1.

In the method *Strat. b,* the strata consisted of the groups of Material 17 applied to the grouping method. They gave 71 strata interpreted as normal or poorly productive forest land (cf. Table 42.1). Two field plots per stratum were selected to allow about 142 to fall to land-use classes I and II. There were 60 repetitions to obtain 60 different field-plot samples. The first-hand results (proportions and mean volumes) and the variances based on repetitions were calculated according to the principles described above.

The selection of the field plots of *Strat. b* was performed with replacement. For practical reasons, this was done by combining the field plots of two repeated samples of Material 17 to form one repeated sample of method *Strat. b.* Each of the 30 samples of Material 17 formed a part of a combination on 4 occasions. Thus, 60 combinations resulted altogether. The design of the method *Strat. b* is comparable with that of the grouping method used with Material 19. Corresponding to the method *Strat. a,* the material under the method *Strat. b* is termed Material 21 (cf. Table 42.1) and the results obtained by the application of the method are presented in Appendix 2.

43. Calculations based on simple random sampling

Random-sampling procedure was applied to Materials 3 and 14 with two sample sizes and to Material 17 with one sample size (see Fig. 411.1 and Table

Table 42.1. Test materials of different methods and their comparability
Taulukko 42.1. Eri menetelmien testiaineistot ja niiden vertailukelpoisuudet

Row[1]) *Rivi[1])*	Grouping method *Ryhmitysmenetelmä*			Strat. a			Strat. b			Random sampling *Satunnaisotanta*		
	Material *Aineisto*	No. of repet. *Toistoja*	No. of groups[2]) *Ryhmiä[2])*	Material *Aineisto*	No. of repet. *Toistoja*	No. of groups[2]) *Ryhmiä[2])*	Material *Aineisto*	No. of repet. *Toistoja*	No. of groups[2]) *Ryhmiä[2])*	Material *Aineisto*	No. of repet. *Toistoja*	No. of groups[2]) *Ryhmiä[2])*
1	2	20	65									
2	3	20	65							4	20	65
3	13	20	131									
4	14	20	131							15	20	131
5	17	30	71							18	30	71
6	19	30	142	20	20	11	21	60	71			

[1]) The test materials of same row refer to equal forest conditions
[1]) *Saman rivin aineistoilla metsäolosuhteet ovat yhtäläiset*

[2]) Refers to groups interpreted from aerial photos as normal or poorly productive forest land
[2]) *Viittaa ryhmiin, jotka on tulkittu ilmakuvilta metsä- tai kitumaaksi*

411.1). Sample sizes were determined according to the following procedure: the random sampling was continued until the predetermined number of plots interpreted from aerial photos as normal or poorly productive forest land was counted. The number of plots interpreted to be other land-use classes varied. It was ensured by this procedure that the estimates of internal characteristics of forest land (e.g. mean volume on forest land) were based on approximately equal numbers of field plots in every repetition.

The materials defining the application of random sampling were termed Materials 4, 14 and 18. Material 4 consisted of the Material 1967/*Interpreter b* combination, with 65 field plots interpreted as land-use classes I or II (see Fig. 411.1). Material 14 similarly consisted of the combination of Material 1967/*Interpreter a*, with 131 field plots falling to land-use classes I or II. Finally Material 18 was based on the combination of Material 1968/*Interpreter a*, with 71 field plots on normal or poorly productive forest land. The correspondence of the materials to those of other methods and the number of repetitions were presented in Table 42.1.

44. Assumptions for simple uniform systematic sampling

The difficulties involving the variances in systematic sampling are well known. Experiments with the variances based on repetitions require large bodies of material, the acquisition of which was not considered possible for the present study. However, systematic sampling is commonly used for the inventorying of large forest areas in Finland, which means that assessment of the grouping method against systematic sampling is one of the major interests of the present kind of study. As the acquisition of a special body of material for systematic sampling was not considered possible, the test materials described in Chapter 3 were applied in a simulative manner. For this purpose some basic assumptions concerning the variances were necessary. Their feasibility could be checked to a certain extent through the conclusions obtained in other studies.

The first assumption in the study of systematic sampling here was that the field plots are located equidistantly over the area undergoing the forest inventory. Second, each field sample plot was assumed to represent a square in the same way as illustrated in Fig. 2234.1 (p. 32). Third, each square represented by a field plot was considered a stratum. This means that the total area was thought to be divided into strata of equal-sized squares, from each of which one field sample plot was to be selected. Fourth, it was assumed for variance calculations that the field plot was drawn by random selection from each stratum to constitute the field sample. Assuming that the variance within

the squares (strata) was known, the sampling variance could have been calculated for the systematic sample using the equations valid to stratified samples.

In order to get an idea of the precision due to systematic sampling, the variance within the assumed squares had to be estimated. On logical grounds and also on the basis of earlier studies (e.g. NYYSSÖNEN & KILKKI 1966 and NYYSSÖNEN *et al.* 1967), it could be concluded that the variance within strata (squares represented by field plots) depended greatly on the extent of the stratum areas. The relation of the variance within an area (a square) represented by a field plot to that obtainable for total area by random sampling was studied with the aid of the test materials. Since material was not specifically collected for this purpose, the studies had to be based on the assumptions illustrated in Fig. 44.1.

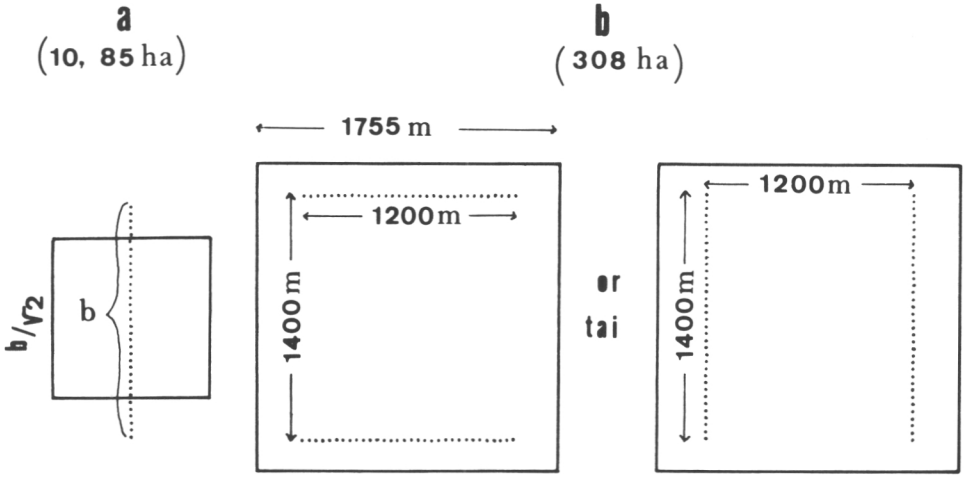


Fig. 44.1. Estimation of variance within a square
Kuva 44.1. Neliön sisäisen varianssin estimoiminen

It was assumed that the variances within the squares could be estimated by means of the plots of line sections of certain length. The handicap was that the length of line section was judged subjectively, based on theoretical considerations. Another fact causing uncertainty on the method was that, in the procedure, the sample plot representing a square was assumed to be selected randomly whereas the central plot of each square would have been in accordance with the design of systematic sampling originally suggested.

It has been usually expected that centrally selected sample plots yield smaller sampling variance than those selected randomly from each square. This is because of a distinct autocorrelation between the neighboring plots, the existence of which has been shown (e.g. by NYYSSÖNEN *et al.* 1967, p. 38). There can, however, be exceptions. If the location of the forests and their characteristics follow a pattern with a certain wave length and the sides of

the squares are about the same length or its integral multiple, the central location may cause high systematic errors, which are not possible if random sampling within strata (squares) was applied. In any case, the results obtained by the procedure explained here coincided fairly well with those presented in an earlier study, as is shown below in Section 53.

5. EFFICIENCY OF THE GROUPING METHOD IN COMPARISON WITH OTHER METHODS

51. Comparability of different methods

Efficiency is often regarded as the most important criterion in comparing different inventory methods. The evaluation of the grouping method in this respect was based on comparisons of the method with double sampling for stratification (methods *Strat. a* and *Strat. b*, p. 64) and one-phase systematic sampling. For technical reasons, the comparisons were extended to include simple random sampling in relation both to the grouping method and to systematic sampling.

Two conditions should be met when making a comparison of the efficiency of different methods. First, the methods to be compared should be applied with the equal relative degree of proficiency. The relationship to the optimum in the application of a method is affected by the size, shape and location of the sampling units, the operational arrangements concerning various phases (cf. Fig. 21.1), the degree of expertise, etc. Second, the methods should be compared at the same level of total inventory cost.

A good solution for an efficiency comparison would be to derive precision as a function of total cost. After this has been done, the comparison of different methods would be easy. Reaching this objective requires, however, information not obtainable in the test materials. Consequently, another procedure was applied. Many different inventory situations were simulated for the application of the grouping method. The efficiency of the grouping method and the corresponding efficiencies of the other methods were calculated in each inventory situation. It was then possible to draw some conclusion as to the factors affecting the efficiency by comparing the respective efficiencies obtained in the various inventory situations.

According to the above it should be questioned how the comparability of different methods as applied in the tests is in respect of the optimum application of the methods. Attention is given here only to the quality and geographical pattern of sampling units.

It has been found (e.g. by NYYSSÖNEN & VUOKILA 1963) that the efficiency of stratified sampling in relation to random sampling increases with increased size of the sampling unit. The increase in the sampling unit had a similar effect on the corresponding relation between systematic and random sampling, as can be concluded from the study made by NYYSSÖNEN *et al.* (1967). Because the effect of the size of sampling unit on the efficiency of the grouping method can be expected to be much the same as on stratified sampling, it can be concluded that the size does not much affect the comparability of the above methods.

In one-phase sampling consisting only of field plots, the equidistantly uniform sampling is usually regarded as the most efficient if cost per field plot is judged independent of the sample design. The consideration of traveling costs, however, leads to the need for a concentration of sampling units. Concentration has been applied for instance in national forest inventories in North-European countries. It has also been suggested that it should be applied to smaller inventories (e.g. NYYSSÖNEN, ROIKO-JOKELA & KILKKI 1971).

Concentration of field plots is possible also in connection with the grouping method, as was tested in the forest inventory of northern Finland (POSO & KUJALA 1971, p. 8). This means that the relation of efficiencies of the grouping method and systematic sampling need not change when shifting from unrestricted random sampling by groups or strata and from equidistant systematic sampling to the respective concentrated samplings. In fact, just such independence was assumed to be true in the efficiency comparisons of all the methods.

As stated above, the efficiencies of the methods can be compared when total costs are equal. The required procedures in equalizing the costs of different methods are rather complex and require many basic assumptions. More attention to the problem will be paid in later sections.

52. Grouping method compared with double sampling for stratification

The grouping method and double sampling for stratification are statistically very close to each other (see Fig. 21.1, p. 25). If the number of sample plots in both methods is equal, the total costs of the methods can be assumed also to be equal. The efficiency comparisons could, therefore, be made simply

on the basis of the variances. In the case of double sampling for stratification, two stratum sizes were examined. The variances based on repetitions, on the Material 19 (grouping method) and on the Materials 20 and 21 (*Strat. a* and *Strat. b*, see p. 64), are presented in Table 52.1.

Table 52.1. Comparison of variances calculated by different methods
Taulukko 52.1. Eri menetelmillä laskettujen varianssien vertailu

Class being studied *Tutkittava luokka*	Grouping method		Strat. a		Strat. b	
	Area proportions, % — *Pinta-alaosuudet, %*					
	p	v_p	p	v_p	p	v_p
Forest land *Metsämaa*	79	1.55	79	1.11	79	1.82
Site-fert. class *Kasvupaikkaluokka*	25	9.31	25	9.32	25	7.57
Treatment class *Kehitysluokka*	12	5.05	12	8.79	12	8.19
	Mean volumes — *Keskikuutiot*					
	y	$v_{\bar{y}}$	y	$v_{\bar{y}}$	y	$v_{\bar{y}}$
Total area *Koko alue*	78	5.2	79	6.1	78	3.8
Forest land *Metsämaa*	99	11.4	100	12.2	98	9.6
Site-fert. class *Kasvupaikkaluokka*	99	63.3	100	56.3	98	51.0
Treatment class *Kehitysluokka*	99	89	100	96	98	84
	Mean volumes on forest land — *Keskikuutiot metsämaalla*					
	y	$v_{\bar{y}}$	y	$v_{\bar{y}}$	y	$v_{\bar{y}}$
Pine — *Mänty*	25	8.5	26	11.2	25	8.1
Spruce — *Kuusi*	53	10.3	53	10.8	53	8.7
Broad-leaved — *Lehtip.*	20	3.5	20	3.8	20	5.8
Pooled relative variances *Painotetut suhteelliset varianssit*		100		109		101

The proportion of forest land is an exceptional characteristic because both the groups of the grouping method and strata of methods *Strat. a* and *Strat. b* were totally homogeneous in respect of the photo-interpreted land-use class. This means that the variances of the proportion of forest land (see figures 1.55, 1.11 and 1.82 in Table 52.1) should be approxi-

mately equal. The differences between the figures were therefore regarded to originate in random variation. Accordingly, it is probable that there exists appreciable random variaton also due to other figures of Table 52.1. This means that making a comparison of the methods for estimating a single characteristic was not regarded as feasible on the basis of Table 52.1.

Because of the insufficient precision of the figures in Table 52.1, a pooled variance was calculated covering all 8 characteristics for each method. Each characteristic was weighted equally and the pooled variance of the grouping method was denoted by a figure 100. The corresponding variance of *Strat. a* was 109 and of *Strat. b* 101. Accordingly, the grouping method and *Strat. b* (with 2 field plots per stratum) were almost equally efficient while *Strat. a* (with about 13 field plots per stratum) was about 9 % less efficient.

In theory, the variances within groups should be smaller than the variances within strata, and the variances of the larger strata (of *Strat. a)* larger than those of the smaller strata (of *Strat. b*). This means that the results in Table 52.1 were, on average, in conformity with theory. The superiority of the grouping method does not, however, apply to all characteristics. As noted above in connection with the proportion of forest land, the internal variances estimated by different methods can be expected to be equal in so far as the groups and strata are totally homogeneous with regard to the photo interpretations. If the correlation between photo and field estimations has decreased, the differences between the efficiencies of the methods in Table 52.1 would become smaller; conversely, with increasing correlation the differences would increase.

The efficiency of the grouping method and the double sampling for stratification with 2 field plots per stratum (*Strat. b*) were stated, on the basis of Table 52.1, to be equal. One problem, which was not studied here, is to determine the effect of the size of the population and the sample on the relative efficiency of different methods. It is possible that the problem may have considerable practical importance and it is therefore illustrated further through a theoretical example.

In the example, the grouping method is compared with *Strat. b* (2 field plots per stratum). For both methods, 60 photo plots were assumed to be interpreted. They were divided into 10 groups or 5 strata with 6 plots per group or 12 plots per stratum, as illustrated by a simple drawing:



It was assumed that two adjacent groups in sequential order constituted one stratum. Further, it was assumed that the extreme values of the groups corresponded to the two extreme values of the stratum. The question to be illustrated is: what is the degree of probability that the extreme values will be included (a) in the sample of 10 field plots drawn by the grouping method and in that drawn by double sampling, with two field plots per stratum? The proportion of probabilities Pr (gr) / Pr (*strat. b*) was found to be 663:

$$Pr\ (gr) = (1/6)^{10} = 0.605 \cdot 10^{-8}$$

$$Pr\ (strat.b) = (1/12)^{5}\ (1/11)^{5} = 0.401 \cdot 10^{-11}$$

$$\Rightarrow\ Pr\ (gr) / Pr\ (strat.b) = 663$$

The example shows that in some respects the grouping method is subject to more erroneous results than double sampling for stratification. The problem calls for further study. It seems probable, however, that the importance of extreme values increases for smaller samples and lower correlations between photo and field estimations.

53. Systematic compared with simple random sampling

The variance of equidistant systematic sampling was estimated on the basis of variances within the line sections of certain length (cf. Fig. 44.1, p. 67), applying the material obtained from four tracts (cf. Fig. 311.3, p. 38). The proportion of the variance to that calculated by equations suitable for simple random sampling applying all the plots of the four tracts is presented in Fig. 53.1 as a function of the area represented by one field plot.

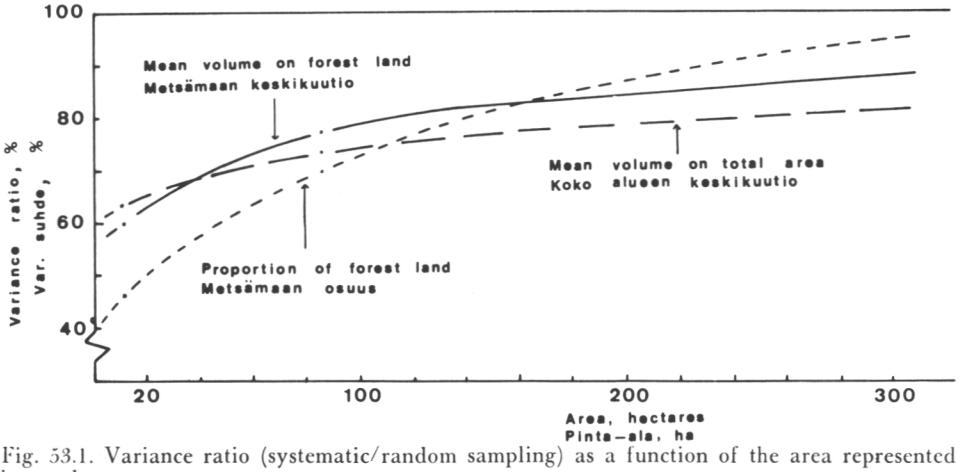


Fig. 53.1. Variance ratio (systematic/random sampling) as a function of the area represented by a plot
Kuva 53.1. Variansissuhde (systemaattinen/satunnaisotanta) koealan edustaman pinta-alan funktiona

Despite the uncertainties inherent in the variances of systematic sampling, the figure was assumed correct for the conditions of the test material. However, it can be expected that the composition of forests would affect greatly the proportion of variances presented in Fig. 53.1. As the results of national inventories show, the composition of forests varies to a great extent from one district to another. Accordingly, Fig. 53.1 should be regarded as specific to the composition of the test material applied.

The variance ratios in Fig. 53.1 were compared with those presented by NYYSSÖNEN & KILKKI (1966, pp. 23—24) and NYYSSÖNEN *et al.* (1967, pp. 31—33). The maximum distance between the plots in their experiments was 300 metres, one plot thus representing 9 hectares. When a plot was 400 square metres in size, the variance ratio of uniform systematic and simple random sampling was about 0.70 in estimating the mean volume of total area. If the size of a plot was increased to 900 m^2, the variance ratio was a little smaller. In Figure 53.1, the respective ratio, when one plot represented 10 hectares, was 0.64. The fairly small differences are influenced by the fact that the study area of NYYSSÖNEN *et al.* was entirely forest land whereas the material on which Fig. 53.1 was based included other land-use classes. Against this background, the ratios obtained from the different studies can be regarded as being very close to each other. Furthermore, the form of the volume curve in Fig. 53.1 is confirmed by the results of the study referred to above. With regard to proportions, the conditions were less favorable for comparison. Anyway, the results by NYYSSÖNEN & KILKKI (1966, pp. 23—24) could not be regarded as contradictory to those of Fig. 53.1.

It was assumed that, in the estimation of the efficiency ratio between systematic and random sampling, the cost per plot was equal in both sampling designs. This assumption is not correct, but it does not cause any considerable error in the final efficiency ratio calculated according to the following equation:

$$\frac{\text{efficiency of grouping method}}{\text{efficiency of random sampling}} : \frac{\text{efficiency of systematic sampling}}{\text{efficiency of random sampling}} = \frac{\text{efficiency of grouping method}}{\text{efficiency of systematic sampling}}$$

The above proportion shows that the efficiency of random sampling was used only as a measure in order to compare the efficiency of the grouping method with that of systematic sampling, and therefore the cost assumption of random sampling did not affect the final ratio in so far as the cost assumptions for random sampling in both cases were equal.

On the assumption of equal costs per plot both in systematic and in random sampling, the efficiency of systematic sampling in relation to random

sampling could be obtained from Figure 53.1 as the inverse of the respective variance ratios.

54. Grouping method compared with simple random sampling

541. Phase 1

The efficiency of the grouping method in relation to that of simple random sampling was estimated in two phases, as explained in Figure 541.1.

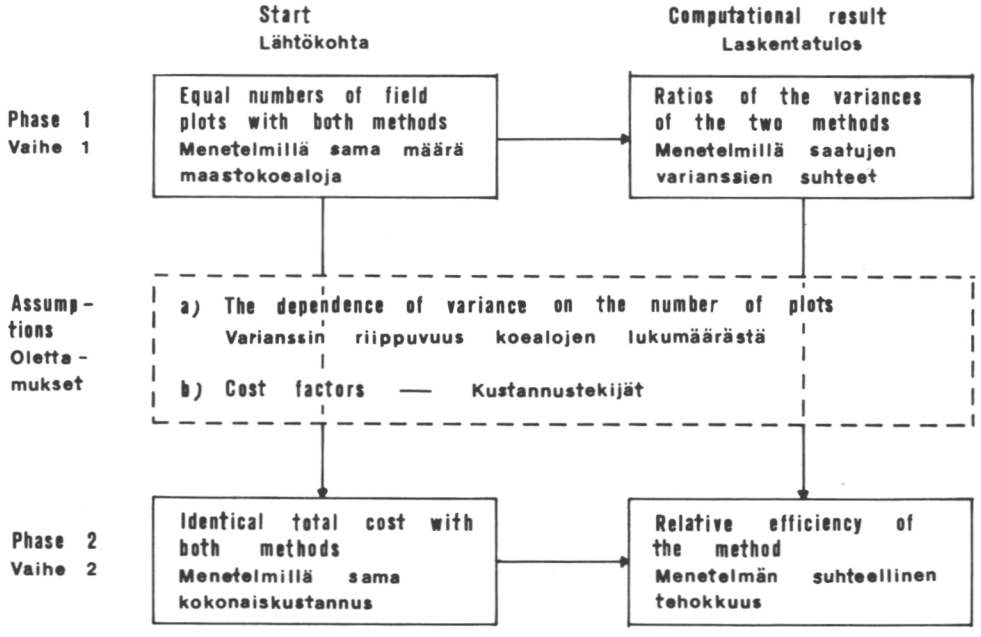


Fig. 541.1. Deriving the comparable efficiencies
Kuva 541.1. Vertailukelpoisten tehokkuuksien muodostaminen

The directly comparable variances were calculated by repeated samples from Materials 3, 14 and 17 for the grouping method and from Materials 4, 15 and 18 for random sampling, as described in Section 43 and in Table 42.1. In fact, the repetitions made by the grouping method from Materials 2, 13 and 19 were also included in the comparison. This was justified because the use of Material 2 instead of 3 and Material 13 instead of 14 in deriving the repetitions for random sampling could be expected to produce equal variances. The variances of random sampling corresponding to the variance of the

grouping method based on Material 19 was derived by dividing the variance of random sampling based on Material 18 by two, corresponding to the ratio of the number of respective sample plots. An example from the resulting variances is given in Table 541.1, concerning the proportion of forest land only.

Table 541.1. Example of calculating variance ratios
Taulukko 541.1. Esimerkki varianssisuhteiden laskemisesta

Materials to be compared *Vertailtavat aineistot* Random sampling/ Grouping method *Satunnaisotanta/ Ryhmitysmenetelmä*	No. of repetitions *Toistoja*	No. of field[1]) plots in random sample *Maastokoealoja[1]) satunnaisotoksessa*	Variance of proportion of forest land, in percentage *Metsämaaosuuden varianssi prosenteissa*		Variance ratio *Variansisuhde*
			Rand om sample *Satunnaisotanta*	Group. method *Ryhm. menetelmä*	
4/2	20/20	88	19.69	1.77	11.12
4/3	20/20	88	19.69	4.14	4.76
15/13	20/20	177	7.25	1.82	3.98
15/14	20/20	177	7.25	2.79	2.60
18/17	30/30	88	17.53	3.97	4.42
18/19	30/30	175	8.76	1.55	5.65

[1]) Plot numbers has been used as weights in calculating of pooled variances
[1]) *Koealojen lukumääriä on käytetty painoina laskettaessa keskimääräisiä variansseja*

The variances obtained by one method for different materials were pooled. The ratio was calculated according to the pooled variances as shown in the illustration based on Table 541.1.

$$\frac{\text{Var.of rand.sampl.}}{\text{Var.of group.meth.}} = \frac{88(19.69+19.69)+177(7.25+7.25)+88\cdot 17.53+175\cdot 8.76}{88(1.77+4.14)+177(1.82+2.79)+88\cdot 3.97+175\cdot 1.55} = 4.65$$

The ratios of the pooled variances for different characteristics were given in Table 541.2. The variance ratios in brackets refer to the Materials 13, 14 and 19, in which the number of field plots was approximately twice the remainder. The purpose of separating these Materials for special observation was to provide an opportunity to study the effect of size of field sample on the efficiency of the method.

Codes used in Table 541.2 (see KUUSELA & SALMINEN 1969, pp. 16—28).

Land-use classes:

1 = forest land
2 = poorly productive forest land
3 = waste land
4 = agricultural land
7 = water

Table 541.2. Ratios of variances based on equal number of field plots
*Taulukko 541.2. **Yhtä suuriin** maastokoealamääriin perustuvien varianssien suhteet*

Class surveyed *Inventoitava luokka*	Code of area class or tree species — *Pinta-alaluokan tai puulajin koodi* Ratio of variances (random/grouping) — *Varianssien suhde (sat.ot./ryhm.)*								
	1	2	3	4	5	6	7	8	1—8 (mean) *(keskim.)*
A. Area proportions — *Pinta-alaosuudet*									
Land-use class *Maaluokka*	4.65 (3.77)	1.05 (1.41)	1.26 (1.59)	6.85 (6.20)			18.77 (13.36)		6.65 (5.20)
Land class *Alaryhmä*	4.06 (3.78)	0.95 (1.11)	2.82 (3.15)						3.46 (3.36)
Site-fertility class on forest land *Kasvupaikkaluokka metsämaalla*		0.89 (0.75)	1.27 (1.28)	0.93 (0.94)	1.08 (1.33)				1.07 (1.06)
Treatment class on forest land *Kehitysluokka metsämaalla*	0.73 (0.77)	1.14 (1.67)	1.42 (1.09)	0.69 (1.10)	1.04 (1.38)	0.94 (0.95)	1.04 (0.88)	1.02 (1.46)	0.98 (1.21)
B. Mean volumes — *Keskikuutiot*									
Class surveyed *Inventoitava luokka*	Code of area class or tree species — *Pinta-alaositteen tai puulajin koodi* Ratio of variances (random/grouping) — *Varianssien suhde (sat.ot./ryhm.)*								
	1	2	3	4	5	6	7	8	1—8 (mean) *(keskim.)*
The whole area *Koko alue*									4.73 (4.25)
Land-use class *Maaluokka*	1.99 (2.04)	0.45 (0.85)							1.94 (2.00)
Land class on forest land *Metsämaan alaryhmä*	1.26 (1.11)	1.63 (1.61)							1.36 (1.25)
Site-fertility class on forest land *Metsämaan kasvup.luokka*		1.33 (1.22)	1.00 (1.21)	1.40 (1.56)	1.34 (1.73)				1.22 (1.36)
Treatment class on forest land *Metsämaan kehitysluokka*	1.98 (1.24)	1.07 (1.36)	1.26 (1.35)	1.72 (2.14)	0.96 (0.74)	0.77 (0.66)	1.45 (1.87)	1.02 (1.21)	1.20 (1.30)
C. Volume proportions — *Kuutio-osuudet*									
Tree species *Puulaji*	0.67 (0.60)	1.35 (1.21)	1.05 (0.83)						1.10 (0.96)

Land classes:

1 = mineral soils
2 = spruce swamp
3 = pine swamp

Site-fertility classes:

2 = rich sites
3 = damp sites
4 = sub-dry sites
5 = dry sites

Treatment classes:

1 = open regeneration area and seed-tree stands
2 = seedling and sapling stands with standards
3 = seedling and sapling stands
4 = thinning stands
5 = preparatory stands
6 = mature stands
7 = shelter-wood stands
8 = low-yielding stands

Tree species:

1 = pine
2 = spruce
3 = broad-leaved

Code 1—8 (mean) refers to the ratios of mean variances entered in one row and weighted with the area proportion of the relevant area class. An exception is tree species, which is weighted by its own mean volume.

The mean diameter and increment of growing stock on forest land were also studied, although they were not included in the Table. The mean obtained for the former was 19.1 cm with a mean variance of 0.269. The ratio of the variance of random sampling to that of the grouping method was 1.19.

The increment over-correlates with the volume in the present materials. This was caused by the smoothing methods used for estimations of increments of sample plots. The repeated samples with the grouping method yielded a mean increment of 3.77 m^3/ha/year, with a pooled variance of 0.049. Owing to the over-correlation, the ratio of the variances of the methods compared was as high as 1.98.

By comparing the figures with and without brackets in Table 541.2, it can be concluded that the increase in sample size does not have any distinct effect on the ratios of the variances of random sampling and of the grouping method.

542. Phase 2

5421. Factors affecting the comparability of the methods

Before the efficiency of the methods could be compared, the variance ratios in Table 541.2, based on field material of equal size, had to be converted to correspond to identical total inventory costs. With this in view, the following facts had to be taken into account:

(1) The variances of the grouping method calculated for Table 541.2 disregarded the variance of representativeness of the photo plots (cf. gv_2 in Equations 2234.3 and 2234.9, pages 31 and 34). The significance of this variance increases with the size of the square represented by a photo plot (cf. Fig. 2234.1, p. 32). The effect of the variance of the representativeness of photo plots was here taken into account as a coefficient k_1 which was estimated for different sizes of squares. The problem will be dealt with below in Section 5423.

(2) With the same total cost, the random sampling produced a larger number of field plots than the grouping method, since with the former no funds needed to be invested on aerial photos or on their interpretation. The total cost ratios of the methods, assuming equal numbers of field plots, will be dealt with by the coefficient k_2 (Section 5423).

(3) Owing to the larger number of field plots, the distances between the field plots of the random sampling were smaller, and the unit costs of the field plots, accordingly, also lower for random sampling than under the grouping method. The ratio of the plot numbers will be dealt with by the coefficient k_3 (Section 5423).

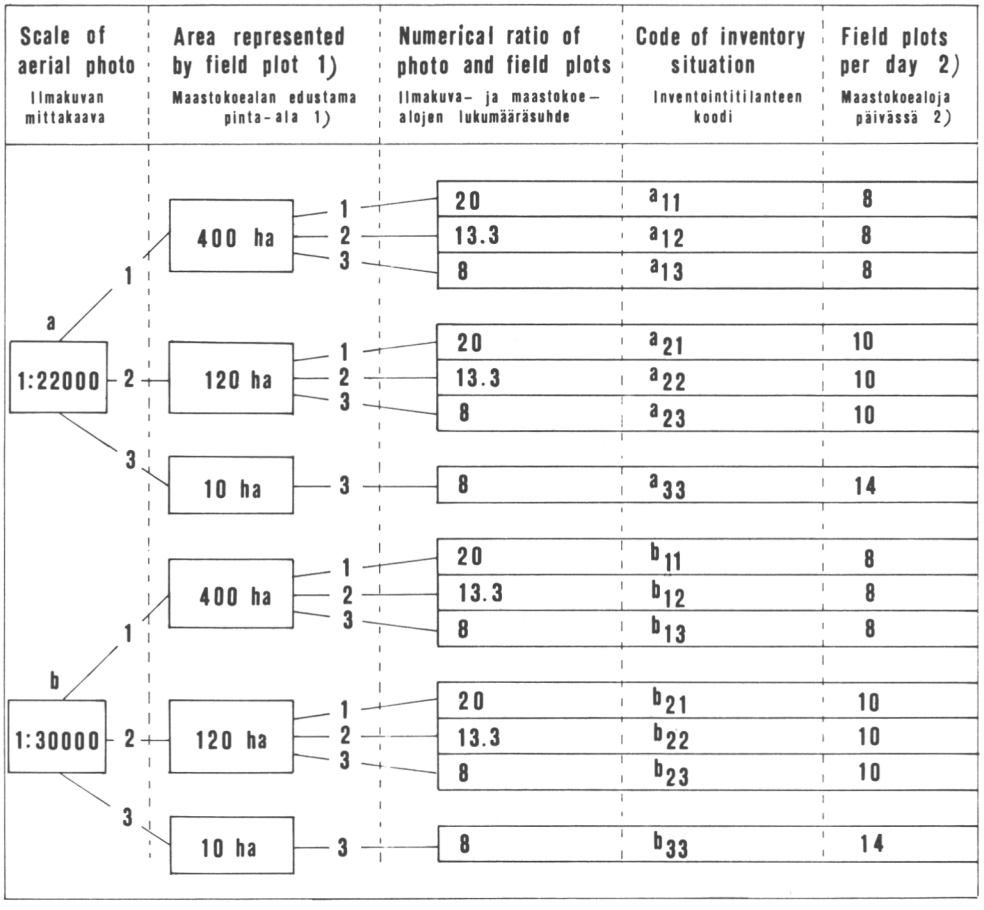
5422. Alternative inventory situations

Compared with random sampling, the grouping method is complicated and has a great number of different details to be defined for the performance of an inventory. The choices to be made depend, of course, on conditions such as the quality of aerial photos, size and shape of the sampling unit, choice and training of an interpreter, methods of interpretation, etc.

In the present study, the efficiency ratio was examined in 14 situations, some of which together with the associated assumptions are presented in detail in Appendix 3 (pp. 128—133). With the aid of the inventory situations, the influence of various factors, such as the ratio of the number of photo and field plots, on the relative efficiency of the grouping method could be studied. The

inventory situations are shown in respect of certain assumptions in a diagrammatic form in Figure 5422.1.

Fig. 5422.1. The alternative inventory situations chosen for examination
Kuva 5422.1. Tutkittaviksi valitut vaihtoehtoiset inventointitilanteet



1) Applying grouping method
1) Käytettäessä ryhmitysmenetelmää

2) Assumed number of field plots measurable by one field group in a day
2) Koealojen lukumäärä, jonka yksi maastoryhmä pystyy mittaamaan päivässä

Common to all 14 inventory situations, the following specifications were assumed:

(1) The population to be studied is that represented by all the test materials.

(2) Precision of photo interpretation is similar to that for the test materials.
(3) The cost of obtaining an aerial photo is mk 12,—.
(4) The cost of photo interpretation is mk 60,—/day.
(5) The cost of field work is mk 240,—/day.
(6) The travelling cost from one field plot to another as a function of distance is as drawn in Fig. 5422.2.

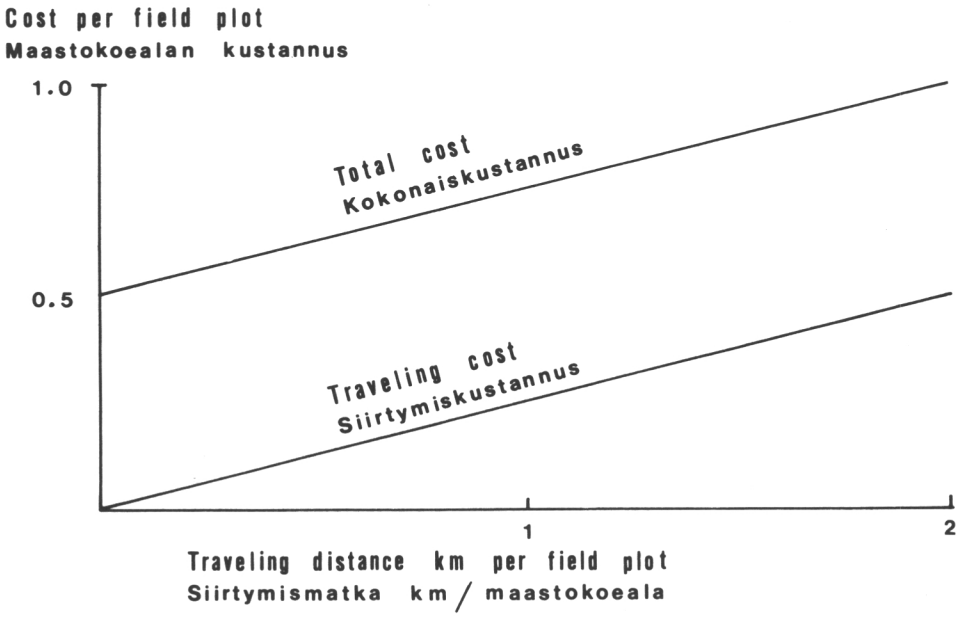


Fig. 5422.2. The dependence of field cost on the distance between field plots
Kuva 5422.2. Maastokustannusten riippuvuus maastokoealojen välimatkasta

Inventory situation aıı corresponded best to the conditions prevailing in the test materials (Chapter 3). Assumptions in addition to the common ones listed above were (cf. Appendix 3):

— Aerial photo 1: 22 000, 18 x 18 cm; the stereoscopic net cover is 28 % of each photo, which means that one photo represents 439 ha which can be viewed stereoscopically.
— One systematically located photo plot represents 20 ha.
— The interpreter is able to interpret 100 photo plots per day, i.e. 2 000 ha in area.
— The ratio of photo- and field-plot numbers is 20.
— The field crew is able to measure 8 plots per day.
— One plot per 400 ha is measured in the field. As the area interpreted per day is 2 000 ha, five field plots are measured for the area.

The application of the grouping method to the above inventory situation produced the following cost items for the area (2 000 ha) interpreted in one day:

aerial photos (2000/439) x 12	=	mk	55,—
interpretation	=	mk	60,—
field plots (5/8) x 240	=	mk	150,—
Total		mk	265,—

5423. Estimation of coefficients k_1, k_2 and k_3

Coefficient k_1

In Table 541.2 (p. 76), the variances obtained by the grouping method were based only on v_1/m, while gv_2/n was missing (cf. Equation 2234.9, p. 34). Coefficient k_1 was calculated to offset this. Consequently, coefficient k_1 was defined as

$$k_1 = (v_1/m + gv_2/n) : (v_1/m)$$

In order to estimate k_1, the relative values for v_1 and v_2 could be derived from Table 541.2 and g could be obtained as a function of the area represented by the photo plot from Fig. 53.1. Estimation of the relative values of v_1 and v_2 was based on the Equation 2234.17

$$v = v_1 + v_2$$

In Table 541.2, the variance obtained by random sampling represented the total variance v, and that obtained by the grouping method represented the variance within groups, v_1. For example, as far as the proportion of forest land was concerned, the Table showed the variance ratio 4.65 ($v = 4.65$, $v_1 = 1.00$). From the above, it is easily found that, in relative sense,

$$v_2 = 4.65 - 1.00 = 3.65$$

For inventory situation a_{11}, coefficient $g = 0.52$ (= variance ratio when $A_i = 20$ ha, see Fig. 53.1) and $n/m = 20$. Accordingly,

$$k_1 = (1 + 0.52 \cdot 3.65/20) : 1 = 1.0949$$

The meaning of coefficient k_1 can be illustrated by an example. According to the above, the variance ratios of Table 541.2 are biased because the variances between groups were not taken into account. In order to correct the bias, the values of Table 541.2 should be divided by k_1. For the proportion of forest land, this means that the ratio 4.65 would change to 4.65/1.0949 = 4.25.

Coefficient k_2

The variance ratios obtained by the methods compared in Table 541.2 were based on equal numbers of field plots. The purpose of coefficient k_2 was to give the *ratio of total costs (grouping method/random sampling) which led to the variance ratios presented in Table 541.2.* The fact that the variance gv_2/n was not included in the Table had to be taken into account separately. This was possible with the aid of coefficient k_1. In different inventory situations, the ratios of relevant total costs could be calculated according to the cost assumptions. For example, in situation a_{11}, coefficient k_2 was calculated for the proportion of forest land as $k_2 = 1.0949 \cdot 265/150 = 1.9343$

Coefficient k_3

Coefficient k_2 showed the total cost ratio (grouping method / random sampling) when the variance ratio (random sampling / grouping method) was that presented in Table 541.2. Coefficient k_3 was taken to show what would be the *ratio of field-plot numbers* (random sampling / grouping method) if the total costs of the methods had been equal. This was assumed to be undertaken by increasing the number of field plots, when applying random sampling, until the total costs of the methods became equal.

The cost per field plot is inversely related to the number of field plots. To take this into account, coefficient k_3 was estimated by the iterative procedure. If the cost per field plot had been independent of the number of plots, then coefficient k_3 would have equalled coefficient k_2. However, according to Fig. 5422.2, the travelling cost was directly proportional to travelling distance, i.e. to the square root of the average area represented by a field plot. Hence $k_3 > k_2$. The iterative procedure was based on the following chain of cause and effect:

— in random sampling the sum of money available for field work increases
=> the number of field plots increases from that applied in the grouping method

=> travelling distances from one field plot to another decrease
=> cost per field plot decreases
=> the number of field plots increases
etc.

Iteration was continued until the number of field plots, assumed to be used in random sampling, ceased to change. The ratio of the resulting number of field plots and the initial number of field plots yielded the desired estimate k_3.

The procedure is illustrated by an example dealing with the proportion of forest land in inventory situation a_{11}. According to coefficient k_2, the area represented by a field plot in random sampling is $1/k_2 = 1/1.9343 = 0.5170$ of the respective area in the grouping method. The travelling cost from one sample plot to another is therefore $\sqrt{0.5170} = 0.7190$ of the corresponding cost (0.5, Fig. 5422.2) under the grouping method. The travelling-cost estimate after the first iteration equals $0.7190 \cdot 0.5 = 0.3595$. The cost per field plot thus becomes 0.5 (cost of measurement) + 0.3595 (travelling cost) = 0.8595. The cost per field plot in the grouping method would equal 1.0000.

The new ratio of the numbers of field plots, k_3, becomes $1.9343/0.8595 = 2.2505$. A new iteration was calculated on its basis:

— the area represented by a field plot was $1/2.2505 = 0.4444$
=> $\sqrt{0.4444} = 0.6666$
=> new travelling cost was $0.6666 \cdot 0.5 = 0.3333$
=> unit cost per field plot was $0.5 + 0.3333 = 0.8333$
=> $k_3 = 1.9343/0.8333 = 2.3213$
=> the area represented by a field plot was $1/2.3213 = 0.4308$
$\geqq \sqrt{0.4308} = 0.6563$
etc.

The final result from this iterative procedure in the example was $k_3 = 2.3386$. Such coefficients were calculated separately for each characteristic chosen for examination and for every inventory situation (Appendix 3).

543. Final estimates

According to random sampling, the sampling variances are inversely proportional to the number of sample plots. As the variance ratios of Table 541.2 presuppose an equal number of field plots, the variance ratio, supposing the total cost of the methods to be equal, could be obtained by dividing the

variance ratios of Table 541.2 by the corresponding coefficient k_3. This procedure resulted in the final estimates for variance ratios in Table 543.1. As the total costs of the methods were equal, the variance ratios directly describe the efficiency of the grouping method in relation to random sampling. For different inventory situations, see Appendix 3.

55. Grouping method compared with systematic sampling

The efficiency of the grouping method compared with systematic sampling could be estimated according to the principles presented on page 73. The relative efficiencies estimated for all 14 inventory situations (Fig. 5422.1) are presented in Table 55.1.

For the comparison, the total cost of the grouping method was first studied; the efficiency of systematic sampling was then examined at the level corresponding to the same total cost. This was facilitated because coefficient k_3 (Section 5423) could be used to define the ratio of the number of field plots in systematic sampling to the number in the grouping method. This procedure was in accordance with the requirement that the cost per field plot had to be assumed equal in comparing both the grouping method and systematic sampling with random sampling.

An example concerning the proportion of forest land in inventory situation a_{11} was taken to illustrate the procedure for constructing Table 55.1. It has already been seen above (in Section 5423) that, in the estimation of the proportion of forest land, k_3 was 2.3386, i.e. with the same total cost the number of field plots in random sampling was 2.3386 times more than in the grouping method. This proportion was retained in the comparison of systematic sampling and the grouping method. This meant that as one field plot in the grouping method represented 400 ha, one field plot in systematic sampling represented only 400/2.3386 = 171 ha. This can also be seen in Appendix $3a_{11}$ (p. 128). Consequently, the efficiency of systematic sampling was read from Fig. 53.1 as the inverse value of the variance ratio at 171 ha. The result was 1.198 (Appendix $3a_{11}$). The efficiency of the grouping method compared with random sampling was 1.99 (Table 543.1). This was divided by 1.198. The quotient 1.99/1.198 = 1.66 (Table 55.1) showed the efficiency looked for.

Efficiency comparisons between random and systematic sampling were not examined for the characteristics site-fertility class, treatment class and tree species as thoroughly as for others although they were marked on Table 55.1. For these characteristics, the curve of mean volume on forest land, as drawn in Fig. 53.1, was applied.

Table 543.1. Efficiency of the grouping method compared with random sampling
Taulukko 543.1. Ryhmitysmenetelmän tehokkuus satunnaisotannan suhteen

Characteristics surveyed *Inventoitava tunnus*		Inventory situation[1]) — *Inventointilanne[1])*												
		a_{11}	a_{12}	a_{13}	a_{21}	a_{22}	a_{23}	a_{33}	b_{11}	b_{12}	b_{13}	b_{21}	b_{22}	b_{23}	b_{33}
Forest-land proportion *Metsämaan osuus*		1.99	2.07	1.97	2.37	2.55	2.59	3.06	2.40	2.53	2.45	2.55	2.75	2.81	3.09
Mean volume on *Keskikuutio*	whole area *koko alueella*	1.96	2.02	1.91	2.22	2.46	2.45	2.93	2.37	2.48	2.38	2.49	2.65	2.66	2.95
	forest land *metsämaalla*	.92	.99	1.03	1.07	1.19	1.29	1.45	1.11	1.22	1.29	1.15	1.29	1.40	1.46
	site-fertility class *kasvupaikkaluokalla*	.56	.61	.63	.66	.73	.79	.89	.68	.75	.79	.71	.79	.86	.90
	treatment class *kehitysluokalla*	.55	.60	.62	.65	.72	.78	.87	.67	.74	.78	.69	.78	.84	.88
	tree species *puulajilla*	.51	.55	.58	.59	.66	.71	.80	.61	.67	.71	.64	.71	.77	.81

[1]) Inventory situations have been described in Fig. 5422.1
[1]) *Inventointitilanteet on selostettu kuvassa 5422.1*

Table 55.1. Efficiency of the grouping method as related to systematic sampling
Taulukko 55.1. Ryhmittymismenetelmän tehokkuus systemaattisen otannan suhteen.

Characteristics surveyed *Inventoitava tunnus*		Inventory situation — *Inventointitilanne*													
		a_{11}	a_{12}	a_{13}	a_{21}	a_{22}	a_{23}	a_{33}	b_{11}	b_{12}	b_{13}	b_{21}	b_{22}	b_{23}	b_{33}
Forest-land proportion *Metsämaan osuus*		1.66	1.74	1.64	1.52	1.67	1.70	1.33	2.10	2.24	2.15	1.67	1.84	1.89	1.35
Mean volume on *Keskikuutio*	whole area *koko alueella*	1.51	1.56	1.47	1.57	1.80	1.78	1.82	1.85	1.95	1.87	1.78	1.91	1.91	1.84
	forest land *metsämaalla*	.77	.84	.87	.79	.90	.99	.84	.94	1.05	1.12	.86	.99	1.08	.85
	site-fertility class *kasvupaikkaluokalla*	.47	.51	.53	.49	.55	.60	.52	.58	.64	.68	.53	.60	.66	.52
	treatment class *kehitysluokalla*	.46	.51	.53	.48	.54	.59	.51	.57	.63	.67	.52	.59	.65	.51
	tree species *puulajilla*	.42	.46	.49	.44	.50	.54	.47	.52	.58	.62	.48	.54	.60	.47

6. CONCLUSIONS

61. Operability of the grouping method

The operability of the grouping method was tested in practice at Suonenjoki in 1969 (inventory of two forest lots of 15 and 180 ha), at Laanila Experiment Station in Lapland (inventory of 17 000 ha), and in the Fifth National Forest Inventory in northern Lapland in 1970 (POSO & KUJALA 1971). In all these experiments, as in the tests for this study, the grouping method worked well when the first-hand results (proportions and mean volumes) were to be calculated. The calculation of precision proved to be problematic, especially when the mean volume of small area classes was in question. The precision of the proportion of forest land and that of the mean volume of total area, however, could be estimated well. The estimation of precision for the mean volume of forest land was quite complex. To estimate the precision of the mean volumes of smaller area classes, no applicable estimators were derived.

An observation of fundamental importance was that the dots marked on the photographs could be placed in the field with sufficient accuracy and rapidity. For photographs of 1: 22 000, the location of a dot was made with an accuracy of about 2 metres. Usually the location of a field plot took 2—7 minutes. No distinct relationship was observed between the time expenditure and the scale of aerial photographs in practice. However, if the time consumption had been increased, the accuracy could have been increased very much.

It became evident in the tests that the photo plots should be marked directly on the photos, thereby preventing possible shifting of the dots in respect of the details on the photograph. Half of the photo plots of the test materials were located indirectly with transparent sheets on which the dots were marked. The sheets were attached to the photographs by tape. When the weather conditions changed, the photos shrank or expanded so that the dots changed their position on the photo. The other half of the photo plots was photographed on the photos when the negative was exposed on light-sensitive paper.

The grading system applied (p. 45) proved to work well. The main purpose of using sliding grading for many characteristics (grades ranged from

1 to 9) was to make it easier to use automatic computers in the grouping of the photo plots. However, the grouping was finally made by mechanical sorters because working out a reasonably good program proved to be too laborious.

The number of characteristics interpreted from the aerial photographs was too large rather than too small (cf. Table 32.1, p. 45). The characteristics with the least use were probably the homogeneity and the treatment class of the stand. It should be noticed when planning photo interpretation that the smaller the number of characteristics the cheaper and probably more precise the photo interpretation.

62. Flexibility

Two kinds of flexibility were differentiated in the introduction (p. 21): computational flexibility and that concerning data collection. In respect of each of them, the grouping method was good. In comparison with other methods, the grouping method could be regarded as superior to double sampling for straticifation particularly in computational flexibility and to systematic sampling particularly in data collection.

The good computational flexibility of the grouping method stems from the fact that each photo-interpreted plot forms an individual computational unit in the final calculation of the inventory results. As explained above, the codes obtainable from maps were given directly to each photo plot. The other parameters were based on field work so that the parameters, such as m^3/ha, were projected from the field plot to all the photo plots belonging to the same group. With automatic computers it was possible and fairly easy to calculate results for any desired combination of photo plots which were equipped with the field-measured data. This did not hold true in double sampling for stratification. For example, the allocation of the volume of a stratum to different area classes (e.g. treatment classes) within a stratum would by no means be a simple thing to do (see Fig. 21.1, p. 25).

Like the other methods based on double sampling, the grouping method was superior to systematic sampling in respect of flexibility in data collection. The period of productive work could be considered as remarkably longer in the grouping method than in systematic sampling because the photo interpretation can be done at times of the year when field work is not feasible. Another reason is that the sample size is more easily adjustable according to the precision or labour capacity. For example, two sets of field plots were used in the inventory of northern Lapland. One was to be measured in

any case. The other was taken for cases when there would be field-work capacity left after the plots of the first set were measured. In the end, 2/3 of the second set were included in the field sample in northern Lapland (POSO & KUJALA 1971).

For conditions where the characteristics of the forests in different regions differ substantially from each other (as in Finland among the 19 Forestry Board Districts), inventory methods applied uniformly in all regions would often lead to a great variation in the precision of the results of different regions. If the inventories of different regions could be adjusted according to precision, the grouping method would probably work very well.

Finally, there exist some specific features of the flexibility in respect of field work. It is characteristic of the grouping method that the set of plots which should be measured in a day can be planned conveniently in the evening before the next day's field work. The travelling routes can be determined according to the paths and obstacles discernable on the photos. The possibility for this kind of planning is smaller with systematic sampling.

63. Efficiency

631. Quality of test materials

The test materials represented a fairly well-stocked forest area in the southern part of Finland. The proportion of forest land was about 75 % and the mean volume of forest land was 96 m³/ha. In respect of these and also the other parameters, the test materials could not be considered exceptional.

Parameters describing the correlation between photo interpretations and field measurements are most important when the efficiency of double-sampling methods is to be studied. To assess the test materials in this respect, the correlation coefficients of the test materials between photo- and field-estimated volumes were compared with those calculated from other materials in which the conditions for photo interpretation were largely the same.

In addition to the results based on the test materials, three other experiments were taken into the comparison. In all the experiments, a variable plot with BAF 1 or a cluster of such plots was applied as the sampling unit. Comparisons of the experiments were made according to the correlation coefficients of those plots falling on forest land.

In the test materials, the coefficient of correlation in examining the correlation of plot volumes, m³/ha, ranged from 0.76 to 0,80. In connection with the Material 1968, *Interpreter a* interpreted almost 300 extra variable plots in order to perform the forest inventories of two forest lots,

one of which was 15 ha and the other 180 ha in size. The plots were located on the photos using millimeter paper and a pin to achieve an equidistant design. For the smaller lot 28 plots and for the larger 64 plots, which were on forest land, were measured in the field. The coefficient of correlation was for the smaller lot 0.87 and for the larger as high as 0.94.

Both coefficients were distinctly higher than those in the test materials, although the photo material applied was exactly the same and the interpreter had not visited the area before his interpretation work. The only difference was that within the forest lots the plots were very close to each other and they were interpreted in a short time period. The quality of the aerial photographs was constant for all the photo plots because they were on the same photograph.

In 1969, *Interpreter a* did more experimental interpretation, this time using photographs of 1: 60 000. This scale was almost 3 times smaller than that applied at Suonenjoki. The area of the experiment was Laanila in northern Finland. It constituted about 17 000 ha in total. Some 1 200 clusters were interpreted from photographs. About 90 of those falling on forest land were measured in the field. Three variable plots (BAF 1) formed a cluster in the shape of an equilateral triangle, each plot 60 metres apart. If the plots in a cluster were regarded as homogeneous, the cluster formed a unit in the interpretation. If the cluster was heterogeneous, each plot could be interpreted separately.

The correlation coefficient calculated on the basis of separate variable plots was 0.83 for Laanila. This coefficient is higher than that obtained from the test materials of this study, although the scale of the photographs was much smaller and the interpreter had never visited the area. The explanation of the difference was the same as above: the interpretation was done in three weeks, the area was compact and all the photographs were taken on the same flight. On the other hand, it seemed that the small scale did not affect very disadvantageously the volume correlation. The reason for this surprising situation is probably that, with a small scale, large areas can be examined in one viewing, which produces a better idea of the range within which the volume on a certain area probably lies and a better possibility of comparing the photo plots with each other.

In 1970 the forest inventory based on the grouping method was extended to encompass the northernmost communes of Finland, Inari, Utsjoki, and Enontekiö. The unit of photo interpretation was a cluster consisting of two variable plots (BAF 1) which were 40 metres apart. The photos used were 1: 60 000, as in Laanila. The total number of clusters interpreted from the aerial photos was 15 441. Of these, 659 were measured in the field; about 250 were located on forest land. The coefficient of correlation was 0.72. In the tests at Laanila, the use of single variable plots had produced almost as high a coefficient as the use of clusters. However, here the coefficient was distinctly

lower than that from Laanila, although the same kinds of photographs were used. The main reason for the difference might have been the extensiveness of the area, which required many flights to photograph it completely. This in turn caused variations in the quality of the photographs. Also, the interpretation took two interpreters a fairly long time (4 months); this might have caused some inconsistency in the interpretation.

In the comparison of the coefficients of correlation of different materials, the values of 0.76—0.80 for the volume of the test material cannot be regarded as exceptionally high. The explanation for the somewhat modest correlation lies in the conditions under which the photo interpretation was performed. These conditions corresponded to those prevailing in the practical interpretation of much larger areas. This was because the photo interpretation of the plots belonging to the test areas was done slowly, as a part of a much larger body of material. It took both of the test materials about 3 months to be interpreted. An additional explanation of the correlation was that the aerial photographs comprised many flights, a factor introducing substantial variation in their quality.

632. Factors affecting the efficiency

It was stated above in section 52 that the grouping method and double sampling for stratification are statistically very close to each other. The efficiency ratios of these methods could be assumed fairly constant, independently of factors such as the number of sampling plots, cost of aerial photographs, etc. Therefore this section deals only with the efficiency of the grouping method in relation to systematic sampling.

The conclusions about the factors affecting the efficiency (the efficiency of the grouping method in relation to that of systematic sampling) were based on the assumptions presented for the inventory situations in Fig. 5422.1 and on some theoretical considerations. To illustrate the effect of various factors on the efficiency, many graphs were drawn. The results obtained, of course, should be interpreted against the many assumptions underlying them.

Average area represented by a field plot as applied to the grouping method.

This factor was fairly close to factors such as the total area subject to forest inventory and the sample size. Fig. 632.1 was drawn according to the assumptions given for inventory situations a_{11}—b_{33} (Fig. 5422.1).

The general impression obtainable from Figure 632.1 is that the area represented by a field plot affected only a very little the efficiency of

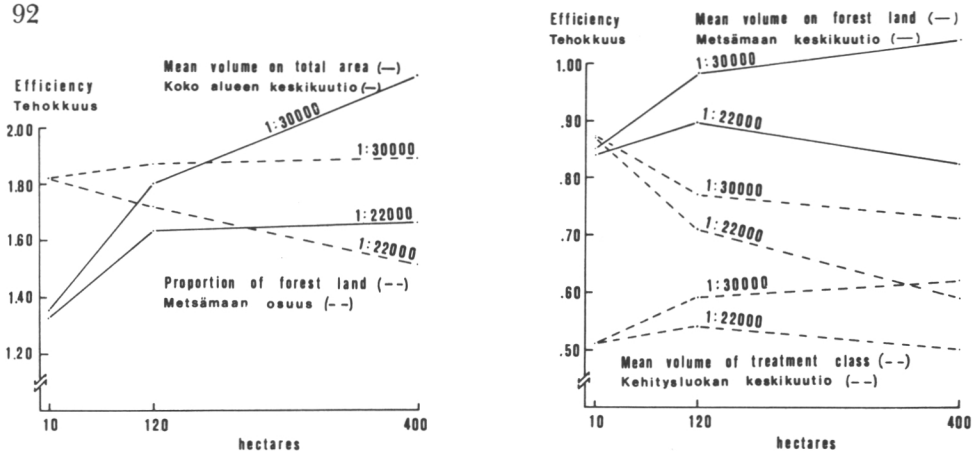


Fig. 632.1. Effect of the area represented by a field plot on efficiency
Kuva 632.1. Maastokoealan edustaman pinta-alan vaikutus tehokkuuteen

the grouping method in relation to systematic sampling within the range 10—400 hectares. The greatest effect was related to the proportion of forest land within the range 10—120 hectares. The fairly high stability of the efficiency in Fig. 632.1 stems from two factors which offset each other. If the acreage of the area changes, the efficiency of both the grouping method and systematic sampling in respect of random sampling change in the same direction. For example, if the area had decreased from 400 to 120 hectares, the efficiency of the grouping method in respect of random sampling would have been increased because of the relative decrease in the cost of photo coverage.

The treatment class in Figure 632.1 was supplied with two lines for both scales. The lower lines were based on the assumption that in estimating mean volume on the treatment class the efficiency of systematic sampling in respect of random sampling is same as when estimating the mean volume on forest land (cf. Fig. 53.1, p. 72). It is probable, however, that the autocorrelation of successive field plots is much smaller for volumes on treatment classes than for volumes on forest land (cf. NYYSSÖNEN & KILKKI 1966, p. 23, NYYSSÖNEN *et al.* 1967, pp. 31—33 and PAYANDEH 1970, p. 273). Accordingly, the lower efficiencies are probably too low. The upper efficiencies were based on the assumption that no autocorrelation is present between field plots that fall on the same treatment class. The true efficiencies can be expected to be between the two lines.

Composition of forests

This refers to a set of parameters describing the forest land and the trees existing on the inventory area. The proportion of forest land, the way the

forest lots are located on the inventory area and the other parameters describing the variation and autocorrelation of various charecteristics within the forest site are probably most important. The conclusions could be derived theoretically and by applying the experience obtained in this and earlier studies. No specific test material with varying composition of forests was applied.

Changes in the composition of forests seem to affect most the efficiency of systematic sampling, and through this the efficiency ratio between the grouping method and systematic sampling. The key parameter is the autocorrelation. The superiority of systematic sampling is based on the autocorrelation of successive field plots. When it decreases, the superiority of the systematic sampling is less pronounced. Consequently, the factors which diminish the autocorrelation of successive field plots tend to increase the efficiency of the grouping method as against that of systematic sampling. Such factors are listed as follows: (1) the proportion of forest land decreases, (2) the distribution of forest land becomes more scattered, and (3) the size and the homogeneity of single stands and treatment units is decreased. Similar conclusions could be drawn from the findings of NYYSSÖNEN *et al.* (1967) and PAYANDEH (1970).

Factors 1 and 2 above affect especially the efficiency ratio when the proportion of forest land and the mean volume on total area are to be estimated. The effect of the factors on the efficiency ratio in respect of the estimation of mean volume on forest land may be somewhat problematic. This is because the decreased proportion of forest land or the increased scattering of forest land tend to diminish the relative precision of the estimate of the proportion of forest land for the grouping method. From the information in Sections 412 and 413, it can be expected that even a small decrease in the precision of the area proportion may have a detrimental effect on the precision of mean volume on forest land.

A contradictory feature exists between the estimation of the mean volume on total area and the mean volume on forest land. It can be illustrated by an extreme example. Assuming that all of the inventory area is forest land (the proportion of forest land equals one), the efficiency ratio in the estimation of total volume is at the minimum. It then equals the efficiency ratio obtained in the estimation of mean volume on forest land. When this situation was applied to the test conditions, the efficiency (grouping method/systematic sampling) came to about 1.1 for photographs of 1: 22 000 and to about 1.4 for photographs of 1: 30 000.

The effect of the third factor on the list, »the size and the homogeneity of single stands and treatment units is decreased», is also problematic and no final conclusion is made here concerning it. This is because the factor probably affects detrimentally the efficiency of the grouping method in addition

to that of systematic sampling. This has its origin in the assumption that the precision of photo interpretation falls when the variation within the stands increases. By weighting this latter side, one could conclude that the efficiency of the grouping method in relation to systematic sampling is best when the forests contain few different tree species and have only slight man-caused disturbances, e.g. in the conditions existing in northern Lapland.

The efficiency of the grouping method is greatly dependent on the coefficient of correlation between photo and field estimations. Consequently, the characteristics which affect the coefficient can also affect the efficiency ratio of the inventory methods. Accordingly, it is possible to conclude that if there existed only a small difference between the mean volumes of different stands the coefficient of correlation, and also the efficiency of the grouping method in estimating mean volume, would be low. The most favorable situation in this respect would be if great variation existed between the stands: if there were plenty of stands with zero volume and others with high volume.

The Fifth National Forest Inventory of Finland (1964—1970) was a practical example of a case in which the local differences have been taken into account when selecting the inventory method. Most forests were surveyed by systematic sampling with tracts as sampling units. The grouping method was applied instead of systematic sampling to an area of about 3 million hectares in the northernmost part of Finland. The forests in northern Lapland contain primarily pine and birch, and are generally in a natural state.

The size of the sample

The efficiency of the grouping metehod in respect of random sampling was examined in Section 541. According to Table 541.2, there was no significant difference in the efficiency obtained by different sample sizes. On the other hand, the number of repetitions was too small to reveal small differences. Theoretically, however, it is possible to conclude that the efficiency increases somewhat as the sample becomes larger (total area is assumed constant). Higher efficiency results because with a larger number of photo plots the construction of homogeneous groups is easier. Also, it becomes possible to adapt the grouping to sub-areas. This is a new aspect of the regulation of the inventory system. In order to increase the precision of photo interpretation, the interpretation should be made by sub-areas, which ought to be as uniform as possible in respect of the composition of forests. Their interpretation from aerial photographs should then be carried out as continuous work. With a larger number of sample plots, smaller sub-areas can be applied and the homogeneity of the sub-areas can be improved.

Sample size affects the efficiency also because of changes in cost relation-

ships. When the number of sample plots increases, the proportion of the cost due to the acquisition of aerial photographs becomes smaller, thereby increasing the efficiency of the grouping method. On the other hand, the travelling costs between field plots decrease and make the cost ratio, field plot to photo plot, smaller. This tends to lower the efficiency of the grouping method.

The efficiency of systematic sampling compared with that of random sampling was dealt with in Section 53. Figure 53.1 (p. 72) showed that the variance ratio, systematic sampling to random sampling, decreases, and efficiency ratio increases when the sample size increases. This conclusion is in accordance with that drawn by NYYSSÖNEN *et al.* (1967, p. 56).

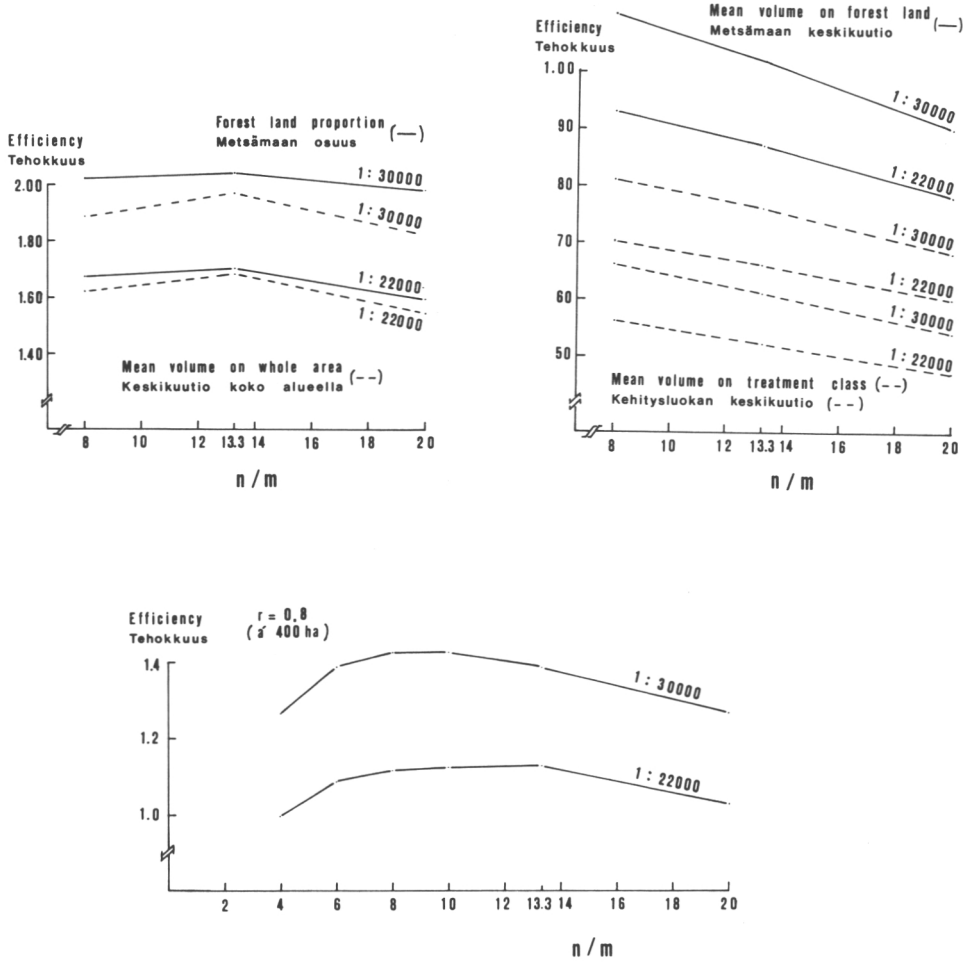


Fig. 632.2. Effect of the numerical ratio (number of photo plots/number of field plots) on efficiency.
Kuva 632.2. Ilmakuva- ja maastokoealojen lukumääräsuhteen vaikutus tehokkuuteen

In total, the effect of sample size on the efficiency (grouping method vs. systematic sampling) is probably rather insignificant because of the contradictory effects of separate factors. Fig. 632.1 can be interpreted as presenting the effect of sample size. An increase in the size of the sample by 100 % corresponds to a decrease in the average area of Figure 632.1 by one half. As can be seen in the Figure, only slight changes take place as a function of the average area represented by a field plot. In addition, the changes in sample size seemed to affect the efficiency of estimating different variables in opposite directions.

Numerical ratio of photo and field plots

The effect of the ratio n/m (number of photo plots to number of field plots) on the efficiency was calculated on the basis of the assumptions presented in Appendix 3 (the first two parts of Figure 632.2). It was also assumed that the coefficient of correlation was 0.8 for volume estimations and that no errors were made in interpreting the are class (e.g. forest land or non-forest land). The third part of Figure 632.2, drawn according to the latter assumption, could represent, for example, the efficiency of the grouping method in relation to that of systematic sampling, when the mean volume of forest land is estimated and when the area of forest land is known exactly.

The Figure showed that the ratio had only a small effect on the efficiency within the range 8—20 when the proportion of forest land and the mean volume on the total area were to be estimated. For the estimation of the mean volume on forest land and the mean volume on treatment class, the ratio 8 distinctly led to the highest efficiencies. The third part of the Figure permitted the conclusion that the form of the lines in the second part is greatly affected by the fact that the area classes were not interpreted without errors.

Coefficient of correlation

The most common parameter used to present the precision of photo interpretation is the coefficient r, representing the correlation between quantitative characteristics estimated from aerial photographs and those estimated in the field. Therefore it was regarded as feasible to examine the dependance between the coefficient of correlation and the efficiency of the grouping method. The results are set out in Figure 632.3.

The coefficient of correlation has a strong dependence on the variance within and between the groups. If the only source of the variance within the groups were the errors in photo interpretation, in other words if the groups were totally homogeneous, and if proportional allocation of field plots was used, the variance within groups could be denoted by $v_1 = (1-r^2)v$.

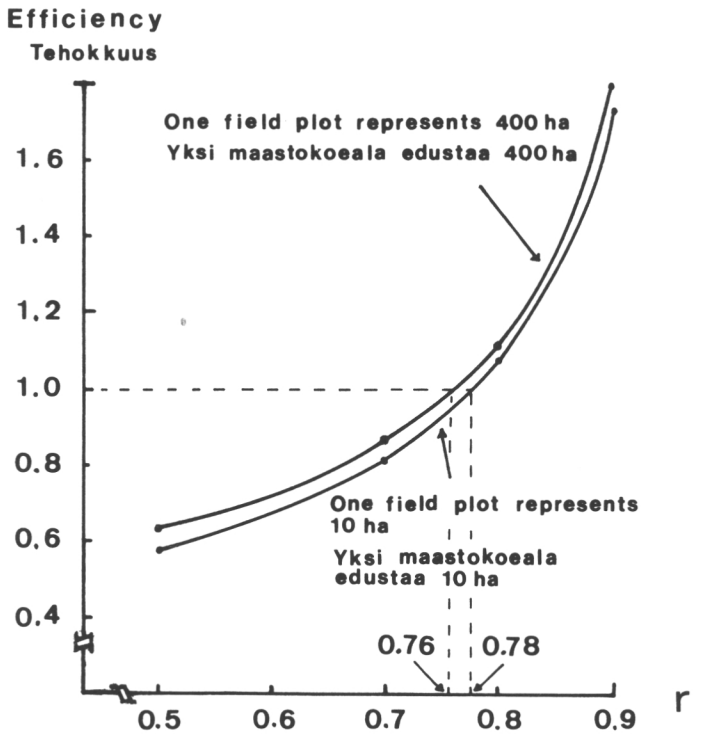


Fig. 632.3. Effect of the coefficient of correlation on efficiency
Kuva 632.3. Korrelaatiokertoimen vaikutus tehokkuuteen

Respectively, the variance between groups would be $v_2 = r^2v$. The equality can be expected to be fairly good for the most important characteristics, such as volume, in respect of which the groups are constructed most homogeneously.

Fig. 632.3 assumed most of the conditions of inventory situation a_{11} and a_{13} to be valid. If the aerial photographs of 1: 30 000 instead of those of 1: 22 000 had been applied, the curves would have been at a somewhat higher level. The figure shows that the critical coefficient of correlation in this case is in the range of 0.76—0.78.

Cost of photo interpretation

It is self-evident that the efficiency of the grouping method increases when the cost of photo interpretation decreases, assuming that the precision remains the same. Applying most of the assumptions of inventory situations a_{13} and b_{13} (one field plot represents 400 hectares, see Fig. 5422.1, p. 79), Figure 632.4 was drawn.

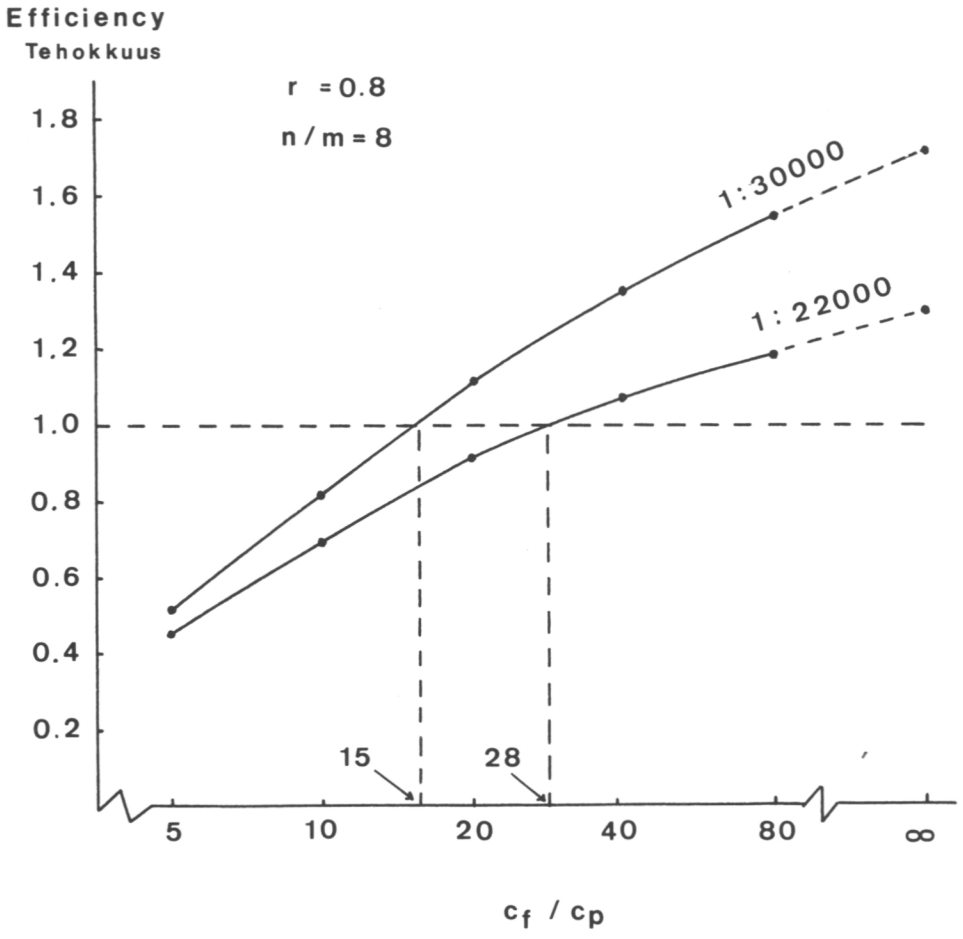


Fig. 632.4. Effect of the cost ratio (a field plot/a photo plot) on efficiency
Kuva 632.4. Kustannussuhteen (maastokoeala/ilmakuvakoeala) vaikutus tehokkuuteen

In Figure 632.4, the ratio n/m (number of photo plots to number of field plots) was assumed to be constant. This means that the curves rise too slowly since along with increases in the cost ratio cf/cp (cost of a field plot / cost of a photo plot) the ratio n/m should also increase in order to maximize the efficiency of the grouping method (cf. COCHRAN 1963, p. 338). The critical values of cf/cp under the assumed conditions proved to be 15 and 28. In other words, the cost ratio, field plot to photo plot, must exceed these before the grouping method becomes superior to systematic sampling.

Cost of aerial photographs

This is a factor which can vary over large ranges from one inventory to another. To make the use of the grouping method possible, it may be necessary in some cases to photograph the inventory area,

or it may be possible to make use of photographs taken for another purpose. In cases when the photos must be taken specifically, there may be possibilities of using them for other purposes besides the inventory. Hence it may not be justified to allocate all the photography costs to the inventory. The different alternatives can be assessed on the basis of Figure 632.5. The values listed for different photos are the cost assuming that the stereo coverage must be bought, i.e., it is not borrowed.

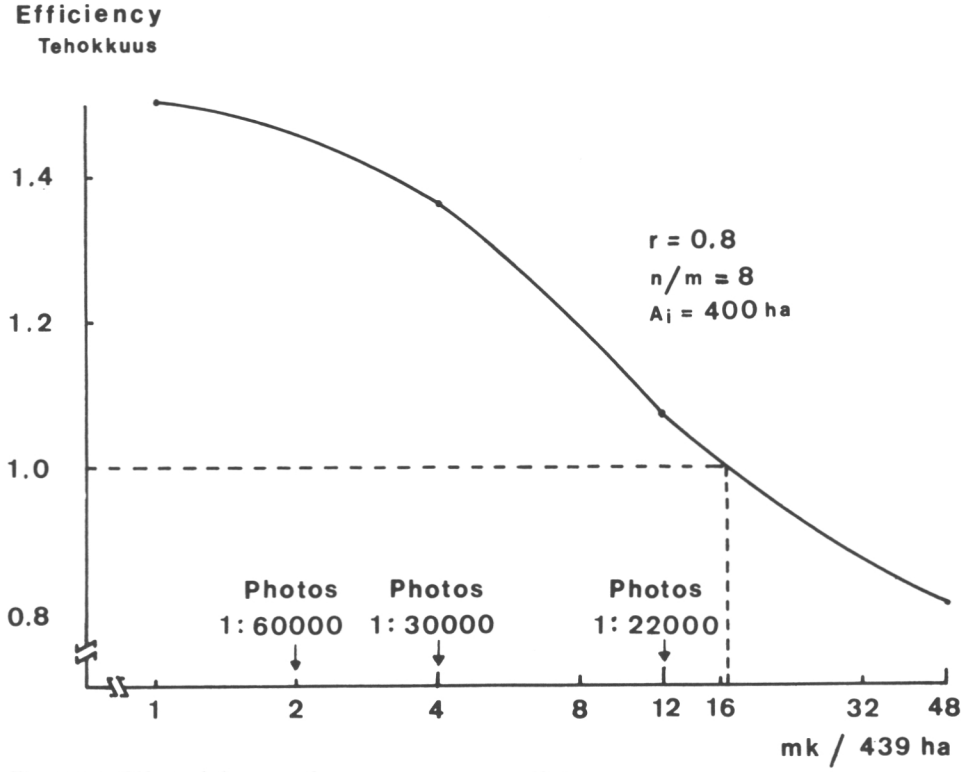


Fig. 632.5. Effect of the cost of stereo coverage on efficiency
Kuva 632.5. Stereopeitosta aiheutuvien kustannusten vaikutus tehokkuuteen

The variable on the abscissa of the figure is Fmk/439 ha. The area 439 ha corresponds to the stereo coverage which is given by one photograph at a scale of 1: 22 000. As the price of one such photograph was assumed to be 12 Fmk, the efficiency of the grouping method can be found from the curve at the point representing the cost of 12 Fmk. The cost of stereo coverage of 439 ha for photos of 1: 30 000 was about 4 Fmk and for 1: 60 000 about 2 Fmk. The efficiency was also calculated by assuming that the photos of 1: 30 000 were used, that their price was 3 Fmk a piece, not 12 Fmk as before, and that

the ratios n/m and cf/cp were 20 and 80 respectively. Assuming other conditions to be the same as in Figure 632.5, the efficiency was calculated to be 1.95.

Objectives of the inventory

The objectives were regarded here to be indicated by the selection of the parameters to be estimated and by the required precisions for them. Figures 632.1 and 632.2 showed that the efficiency of the grouping method is to a great extent dependent on what parameters are to be estimated and what specific importance is given to each of them.

The first parameter to be estimated is usually the total volume. If the objective of the inventory had been to estimate this only, the grouping method would have been greatly superior to systematic sampling. When the number of objectives increases, determining the efficiency of a method in respect of all of them becomes difficult. Some kind of pooling system should be provided. A general conclusion, however, can be made without any further calculations: the efficiency of the grouping method tends to decrease with increases in the selection of parameters to be estimated and the evaluation of the parameters dealing with the most detailed information (e.g. volume by tree species and age classes).

In addition to the objectives concerning the total area are the separate objectives for sub-districts. For example, the requirement for the precision of the volume on the total area may be 2.5 % (percentage of the standard error from the total volume). The volumes are also needed for sub-districts with a precision of 7 %. The latter requirement may be much more difficult to attain than the former.

Shifting from the objectives of total area to those for sub-districts probably increases the relative efficiency of the grouping method. This conclusion stems from the obvious fact that the weight of a single photo plot increases when moving towards smaller sub-districts. This can be illustrated by an example. A small sub-district is assumed. Only 4 field plots would have been fallen on it if systematic sampling had been applied. For the grouping method the number of field plots would have been even smaller, say 2, but the number of photo plots 20. It is evident that the 20 photo plots provided by formally complete data would have given much more reliable results than the 4 field plots. In addition the 20 photo plots may belong to 10 different groups. This means that, in reality, the results obtainable with the grouping method would be based on 10 field plots instead of only 2 (see POSO & KUJALA 1971, pp. 27—30).

633. Grouping method versus other inventory methods

The methods with which the grouping method was compared in the tests were double sampling for stratification and systematic one-phase sampling. The conclusions are restricted to the efficiency of the grouping method in respect of these two methods.

The grouping method is in many respects very close to double sampling for stratification (see Fig. 21.1, p. 25). The only difference in view of the efficiency is that the groups are much smaller than the strata. As a result, the variances within groups are smaller than the variances within strata. The extent of the differences can be concluded to be dependent on two factors: the difference in efficiency is larger the larger the difference between the ranges of the groups and strata are and the higher the correlation between photo and field estimations is. However, the conclusions about the superiority of the grouping method are indisputable only when the size of sample is large. When the size decreases, there is evidence that the efficiency of the grouping method tends to decrease in proportion to that of double sampling for stratification. This, however, was not studied in this paper, with the exception of a small introduction to the problem.

The results obtained for the relationship of the efficiencies of the methods were rather imprecise. This is evident from the illogical variation characterizing the variances of separate estimates in Table 52.1 (p. 70). The results could be regarded, on the whole, to be in accordance with theoretical considerations. When the strata were about 13 times larger than the groups, there was a difference of about 9 % in the efficiency in favour of the grouping method. When the strata were only twice the size of groups, the methods were about equally efficient.

Unlike the methods compared above, the grouping method and systematic sampling are very different from each other. It follows that the calculation of comparative efficiencies was complex and had to be based on many assumptions. The factors affecting the results strongly are the precision of photo interpretation, cost ratios, and the objectives set for the inventory. For specific inventory situations, the procedure used in connection with the inventory situations of Appendix 3 would be applicable. Because of the large variation in the conditions as regards the application of the grouping method, an effort was made to clarify the situation in respect of some of the most obvious factors.

Uses for forestry in Finland have so far been only secondary applications of aerial photographs. Usually the photographs are bought or borrowed for forestry purposes at a fairly moderate cost using photographs which have been taken for other purposes. The two most important sources of aerial photographs are at present the National Board of Land Survey (*Maanmittaushallitus)* and

the Defence Forces. The former takes photographs at scales of 1: 22 000 and 1: 30 000, such as those described in Appendix 3. The scale used by the latter is 1: 60 000. Photos from the Defence Forces were used successfully for the inventory of northernmost Lapland in connection with the Fifth National Forest Inventory.

At present, aerial photography is repeated every three years over the whole of Finland on a scale of 1: 60 000. This makes up-to-date photographs available at all times at 1: 60 000. Other photographs at 1: 22 000 and 1: 30 000 are taken at the same time by two cameras installed in the plane, but not over the whole country. Thus there exist large areas in Finland where no photography is made at 1: 22 000 and 1: 30 000 for as long as 10 years. This brings up the problem of the age of the photographs. This problem could be lessened by co-ordinating the efforts of the forestry users and the institutes which take the aerial photographs.

The precision of photo interpretation obtained in the tests was considered to correspond to that obtainable in the national forest inventories using up-to-date aerial photographs. If the age of aerial photographs increases, the precision of photo interpretation falls. This, of course, affects detrimentally the efficiency of the grouping method (Fig. 632.3, p. 97). It is not likely, however, that the effect of the age of the aerial photographs on the efficiency follows exactly the curves in Figure 632.3. This is due to the fact that the variances within the separate groups are not affected in similar ways. The largest increase in variance probably takes place in the groups which can be interpreted as nearly ready for clear-cutting. If all the photo plots of a separate group had been clear-cut after the photography but before the field work, there would have been a great decrease in the precision of photo interpretation, but it would not have affected detrimentally the efficiency of the grouping method on this part. This might have been what BICKFORD (1961, p. 763) was thinking when he stated that the effect of the age of aerial photographs is easily overestimated.

A very important factor, and the one which should be the first step to be specified, involves the objectives of the inventory. As seen in Figures 632.1 and 632.2, the efficiency varies very much according to the parameter to be estimated. In the estimation of some parameters, the grouping method is much more efficient than systematic sampling, whereas in the estimation of others it is much less efficient. Therefore, the weights given to the estimation of separate parameters are decisive. Because this problem is important and is studied rather little in the literature, it is dealt with here in a somewhat more detailed manner.

The first task is to find out how goal setting for forest inventory works in practice. It may happen that the objectives are fixed according to the method one is most familiar with. The planning system is then adapted to the

results of a method. This creates a danger that those adapted objectives are regarded as real, and the comparisons between different methods are then made on an erroneous basis.

The comparison of different methods in respect of all objectives might be correctly founded if both of the above objectives, those which are original and independent of the method applied and those adapted to a specific inventory method, are used. The problem is, however, too extensive to be treated here in more detail. Therefore the conclusions about the efficiencies of different methods had to be made only in respect of some individual parameters.

The grouping method was distinctly more efficient than systematic sampling for the estimation of the proportion of forest land and the mean volume on total area (Figures 632.1 and 632.2, pp. 92 and 95). This conclusion is in accordance with earlier studies (e.g. NYYSSÖNEN *et al.* 1968). Concerning the mean volume on forest land, there exists a disturbing feature, which was referred to on page 60. As the mean volume on forest land is often regarded as one of the most important parameters to be estimated, an effort was made here to deal with it in more detail.

Errors in photo interpretation between forest and non-forest land proved to be very detrimental for the estimation of the mean volume of forest land by the grouping method. Most mistakes in the test materials proved to be caused by the photo plots which fell on former agricultural land which had begun to be reforested. Another source of error was the divided plots; these were plots which lay on the borderline between forest and non-forest land. The detrimental variance within groups was introduced by the fact that the estimations made in the field and from aerial photographs concerning forest and non-forest land were totally independent on each other and that the divided and undivided plots often had to be mixed in the same group. This was because more importance in the grouping was placed on similarity of other factors (e.g. m^3/ha) than on the proportion of forest land, if some part of the plot was regarded as forest land.

The consequences for mean volume on forest land of the errors in photo interpretation of land-use classes can be illustrated by the following equations (cf. Equation 2233.4):

$$\bar{y}_g = \sum_i^n y_i \; / \; \sum_i^n w_i \quad \text{(grouping method)}$$

and

$$\bar{y}_s = \sum_i^n w_i \bar{y}_i \; / \; \sum_i^n w_i \quad \text{(systematic sampling)}$$

where

n = number of plots
y_i = volume on forest land on a whole sample plot i, m^3/ha
w_i = proportion of forest land on sample plot i
$\bar{y}_i$ = mean volume on forest land on sample plot i, m^3/ha
(on divided plots $\bar{y}_i > y_i$).

The total volumes on forest land can be expressed:

$$y_g = p_g \cdot \bar{y}_g \cdot A \quad \text{(grouping method)}$$

$$= \left(\sum^{n} w_i / n\right) \cdot \left(\sum^{n} y_i / \sum^{n} w_i\right) \cdot A$$

$$\boxed{= \left(\sum^{n} y_i / n\right) \cdot A}$$

and

$$y_s = p_s \cdot \bar{y}_s \cdot A \quad \text{(systematic sampling)}$$

$$\boxed{= \left(\sum^{n} w_i \bar{y}_i / n\right) \cdot A}$$

On the basis of the equations, it can be seen that the mean volume on forest land is greatly affected by the precision obtained for the proportion of forest land when the grouping method is applied. In the case of systematic sampling, there is no effect of the same kind. This difference is important in explaining the rather low efficiency of the grouping method compared with that of systematic sampling. Without the errors in interpretation of forest and non-forest land, the efficiency ratio would have been like that presented in part 3 of Figure 632.2 instead of those presented in parts 1 and 2 of the same figure.

On the basis of the above, it can be seen that the equations for total volume on forest land are practically identical. It is probable that the errors made in the photo interpretation of land-use classes affect only to a small extent the total volume on forest land. This conclusion is based on the fact that the errors take place mostly on open areas or on plots with a small volume. These kinds of mistakes do not affect the estimation detrimentally.

The preceding paragraphs serve as an introduction to the question of the importance of the mean volume on forest land. A related question is the ability of the mean volume on forest land to be replaced by total volume on forest land for forestry-planning purposes.

It was distinctly noticeable in the tests that the terms p_g and $\bar{y}_g$ were in negative correlation to each other in the equation $y_g = p_g \cdot \bar{y}_g \cdot A$. This means that the volume y_g is more accurate than can be expected when considering the errors in p_g and $\bar{y}_g$. If, for instance, $\bar{y}_s$ was more accurate than $\bar{y}_g$, it would not be clear that a more accurate estimate for total volume on forest land could be produced by substituting $\bar{y}_s$ for $\bar{y}_g$. On the contrary, the results of this substitution probably would have been worse. In other words, the mean volume obtained by the grouping method was more valuable in test conditions than that obtainable by systematic sampling. When the true proportion of forest land equals one, the grouping method can be expected to produce a higher efficiency for mean volume on forest land than systematic sampling (cf. part 3 of Fig. 632.2, p. 95).

The parameters characterized by more detailed information than those dealt with above (such as the proportions of and mean volumes on site-fertility and treatment classes and also volumes by treatment classes, cf. Table 541.2, p. 76 and Figures 632.1 and 632.2, pp. 92 and 95) were estimated less efficiently by the grouping method than by systematic sampling in the test conditions. This leads inevitably to the conclusion that the grouping method in its present technical state is usually less efficient than systematic sampling for estimating the parameters within forest land. The conclusion is in accordance with that made by MACLEAN (1963, p. 516).

The comparisons have been dealt with so far as if the efficiency were totally independent of the flexibility. Sometimes, however, it is perfectly realistic to regard the flexibility, especially in data collection, as an auxiliary variable for explaining the efficiency. The presentation of an example representing an extreme case was chosen to illustrate the possible affect. It shows that as a result of better flexibility the efficiencies of the grouping method versus those of systematic sampling tend to be higher than the efficiencies presented in Figures 632.1 and 632.2. The assumptions for the example were:

— maximum length of the field-work season is 4 months
— all workers are whole-year employees
— there is no productive work other than photo interpretation for the time outside the field season
— the number of workers and their salary is independent of the method applied to the inventory.

Under the conditions of the example, it is clear that number of field plots is almost equal in both methods at the same total cost. This would mean that the efficiencies were approximately twice as high as those presented in Figures 632.1 and 632.2 for the test conditions.

64. Towards optimal application

The number of possible combinations of solutions in separate steps of the grouping method (see Fig. 21.1, p. 25) is large. The optimal path, i.e. the set of solutions resulting in highest final efficiency, should be sought specifically for each inventory situation in accordance with the principles applied to the tests. The inventory situation assumed here was that represented by national or other extensive forest inventories. The work towards the optimal set was restricted only to some rather general points which were dealt with to a limited extent in the preceding pages. The conclusions could be based to a large degree on the experiences obtained from the application of the grouping method in connection with the Fifth National Forest Inventory of Finland in 1970 (cf. POSO & KUJALA 1971).

An important step in national forest inventories is the specification of geographical sub-areas. They should be homogeneous in respect of the composition of the forest (e.g. in respect of site and tree species). The quality of the photographical material concerning a sub-area should also be as uniform as possible. This is especially true for the age of the photographs.

The delineation of homogeneous sub-areas helps in achieving the highest possible correlation between photo and field plots. To achieve the full benefit, the photo plots of a sub-area should be interpreted as continuous work, avoiding thereby unnecessary fluctuations in the grading system applied to the interpretation of various characteristics. In addition, the grouping of the photo plots should be made by sub-areas. This requirement prevents the sub-area from becoming too small. The extent of the sub-areas used in Lapland was about 120 000 hectares.

Unrestricted random selection of field plots from among the photo plots leads to a rather uniform distribution of field plots over the whole area. This means that in large inventories the travelling distance from one field plot to another is long, which generates high costs. Therefore the concentration of field plots is a necessary step in the approach to optimum application.

If concentration of field plots is regarded as feasible, the total area should be divided into specific areas of about equal extent. Some of these then have to be selected to serve as concentration areas. For example, systematic sampling with a random start could be applicable to the selection of concentration areas. Only those photo plots which belong to such areas could be accepted for measurement in the field. The concentration areas should always be smaller than the sub-areas. Problems will arise if no photo plot of a group falls on any of the concentration areas; such cases should be handled individually.

The type and quality of aerial photographs is one variable which may have a substantial effect on the efficiency of the grouping method. So far in

Finland the best available up-to-date material is at a scale of 1 : 60 000. The photographs are also cheap (Fig. 632.5, p. 99), and the interpretation of the volumes from them proved to be fairly precise. The coefficient of correlation was about 0.72 in northern Lapland (3 million hectares) and as high as 0.83 at Laanila (17 000 hectares) in the estimation of volumes on forest land. Cooperation with the organizations taking aerial photographs could probably result in some improvement in the quality and in the timing of photography over forest areas from the forest-inventory point of view.

The suggestions made in many earlier papers dealing with the use of aerial photographs for forest inventory are still valid. These include the optimization of factors such as the sampling unit, numerical ratio of photo and field plots, interpretation work, education, etc.

The preceding sections showed that the grouping method is distinctly superior to systematic sampling for the estimation of the proportion of forest land and the total volume on the inventory area. At the same time, it proved to be inferior for the estimation of parameters describing detailed information, such as the proportions of and the mean volumes on treatment classes. These contradictory characteristics make it possible to think of combining the two methods, thereby realizing the advantages of both.

So far, it has always been assumed that the photo interpretation precedes the field work in the grouping method. In practice, however, situations often exist where the inventory performed by one-phase field sampling should be intensified. The problem is how the grouping method could be applied to this kind of situation when the sequence of photo- and field-plot estimation is reversed. This problem is now being studied, together with the possibility of combining the grouping method with systematic sampling, in south-west Finland.

Finally, the national forest inventories must be repeated at certain time intervals. Therefore, the forest inventory could be considered as a continuous system which should be used as a basis for evaluating different methods. This enlargement of the framework raises a new aspect for consideration: the feasibility of applying methods based on remeasurements of a certain proportion of sample plots measured in earlier inventories. It is probable that the principles of remeasuring some plots could be applied fairly easily to the grouping method. This would follow the pattern of the remeasurements which have been applied to double sampling for stratification in the northeastern part of the USA (BICKFORD, MAYER & WARE 1963).

7. SUMMARY

The subject of this study was an inventory method, based on double sampling, called the *grouping method.* Typical of the method is that a large number of plots are interpreted without any prefixed stratification, the photo plots are then sorted into homogeneous groups according to all the photo interpretations, one plot is selected from each group for field measurement, and the results are transferred to all the photo plots (the results of one field plot to all the photo plots of the same group). This procedure provided all the photo plots with independently operative and formally complete data. This made the method extremely flexible computationally. The objective of the study was first to show how the method works and what its capability is in an operational sense, and second to compare the grouping method with normal double sampling for stratification and with one-phase systematic sampling.

The operability of the grouping method proved to be good for the »first-hand» results, i.e. for the proportions of and mean volumes on different area classes. The precision of the results proved to be problematic for the mean volumes on small area classes, e.g. on treatment classes. Even the estimation of the precision for the mean volume on forest land required special attention. The precisions for area proportions and mean volumes on total area could be estimated satisfactorily.

The comparison of the grouping method with double sampling for stratification gave results which conformed with the theoretical considerations. The grouping method was about as efficient as double sampling for stratification with two field plots per stratum. When the size of a stratum was raised to 10 or more, the grouping method was observed to be almost 10 % more efficient. It should be remembered, however, that the result of this comparison depends very much on the selection of the parameters. For example, for the proportion of forest land there should not exist any significant difference in efficiency.

The principal factor favouring the grouping method over double sampling for stratification was concluded to be the good computational flexibility. This flexibility has to be regarded as important because otherwise the delineation of the sub-districts and the combinations for which the results should be

calculated would be an overwhelming undertaking, given the conditions of Finnish national forest inventories.

The comparison of the grouping method with systematic sampling was a complex procedure. Most of the data associated with the costs was not based on special studies but on personal judgement. This judgement was based on experience gained from the Fifth National Forest Inventory in Finland, especially the use of the grouping method in connection with it. It is evident that the reliability of the results is to a great extent dependent on the validity of the judgements.

The grouping method proved to be distinctly superior to systematic sampling in the estimation of the proportion of forest land and the mean volume on total area. It was considered to be a little more efficient also in the estimation of the mean volume on forest land, especially if the proportion of forest land was high. On the other hand, the application of double sampling has been frequently suggested as being the most feasible for the stratification of forested areas. This means that under Finnish conditions the feasibility of the grouping method should increase when the proportion of forest land decreases.

The grouping method proved to be distinctly inferior to systematic sampling in the estimation of parameters such as the proportion of and mean volumes on fertility and treatment classes and the mean volumes on forest land by tree species.

The final conclusion about the feasibility of the grouping method in relation to systematic sampling should be made in respect of the objectives of the inventory. This is a subject which was not dealt with in depth in this paper. It was shown that in the estimation of the mean volume on forest land by the grouping method the estimates of the mean volume on and the proportions of area classes may have a distinct negative correlation with each other. If this were true throughout the area classes, their total volumes would be estimated with better precision than the results obtained for mean volumes and proportions gave grounds to expect.

The experience gained from the study suggested the need to examine a possible combination of the grouping method and systematic sampling. This seemed reasonable because the methods were very different in the efficiency of estimating various parameters. Further study should also be extended to deal with the feasibility of incorporating the technique of remeasured plots in continuous forest inventories.

REFERENCES

Aldred, A. H. and F. W. Kippen. 1967. Plot volumes from large-scale 70 mm air photographs. *Forest Science* 13.4: 419—426. Washington D. C.

Aldrich, R. C., W. F. Bailey and R. C. Heller. 1959. Large scale 70 mm. color photography techniques and equipment and their application to a forest sampling problem. *Photogrammetric Engineering* 25.5: 747—754. Menasha.

Bickerstaff, A. and R. P. Hirvonen. 1969. Forest inventory practices of Canadian provincial and federal agencies. *Canadian Forestry Service.* Information report FMR-X-19: 1—71. Ottawa.

Bickford, C. A. 1952. The sampling design used in the forest survey of the Northeast. *Journal of Forestry* 50.4: 290—293. Washington D. C.

—»— 1953. Increasing the efficiency of airphoto forest surveys by better definition of classes. *Northeastern Forest Experiment Station.* Station Paper No. 58: 1—9. Upper Darby.

—»— 1961. Stratification for timber cruising. *Journal of Forestry* 59.10: 761—763. Washington D. C.

Bickford, C. A., C. E. Mayer and K. D. Ware. 1963. An efficient sampling design for forest inventory: the northeastern forest resurvey. *Journal of Forestry* 61.11: 826—833. Washington D. C.

Bitterlich, W. 1948. Die Winkelzählprobe. *Allgemeine Forst- und holzwirtschaftliche Zeitung* 59.1/2: 4—5. Vienna.

Brock, G. C. 1968. Limitations of resolving power as a measure of image quality in aerial photography. *The Photogrammetric Record* 6.31: 32—40. London.

Cajander, A. K. 1909. Ueber Waldtypen. *Acta Forestalia Fennica* 1: 1—175. Helsinki.

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

Cooper, C. F. and F. M. Smith. 1966. Color aerial photography. Toy or tool? *Journal of Forestry* 64.6: 373—378. Washington D. C.

Cunia, T. 1965. Continuous forest inventory, partial replacement of samples and multiple regression. *Forest Science* 11: 480—502. Washington D. C.

FAO. 1968. Manual for forest inventory operations executed by FAO. *Forestry and Forest Industries Division.* FO: MISC/68: 1—110. Rome.

Ferree, M. J. 1953. A method of estimating timber volumes from aerial photographs. *State University of New York, College of Forestry at Syracuse.* New York.

Grossmann, H. and G. Wolff. 1963. Versuche zur Rationalisierung der Methodik von Holzvorratsinventuren auf mathematisch-statistischen Grundlage. *Archiv für Forstwesen* 12.1: 77—101. Berlin.

Haapamäki, S. 1971. Ilmakuvaustekniikka. *Insinöörijärjestöjen Koulutuskeskus* 71. 2/2: 1—52. Helsinki.

Hakkarainen, J. 1970. Tutkimus ortokuvan valokuvauksellisesta laadusta. *Maanmittausinsinööri* 4: 113—116. Helsinki.

Hedlund, B. 1966. Flygbildteknikens tillämpning vid inventering för långsiktig driftsplanläggning. *Nämnden för skoglig flygbildteknik* 1: 8—18. Stockholm.

Heller, R. C., G. E. Doverspike and R. C. Aldrich. 1964. Identification of tree species on large-scale pancromatic and color aerial photographs. *U. S. Department of Agriculture*, Handbook No. 261. Beltsville, Md.

Hildebrandt, G. 1961. Methoden der Waldinventur im Nordwesten und in den Rocky Mountains der USA. *Allgemeine Forstzeitschrift* 16.1: 21—24. Munich.

—»— 1962. Luftbildauswertung bei Waldinventuren im Gebiet der Sommer- und Nadelwälder. *Allgemeine Forstzeitschrift* 17. 1/2: 20—26. Munich.

Horwitz, L. 1959. *Estimation of totals* (volume, acreage, break downs). Unpubl.

Husch, B. 1971. Planning a forest inventory. *FAO Forestry and Forest Products Studies* 17: 1—120. Rome.

Ilvessalo, Y. 1927. Suomen metsät. Tulokset vuosina 1921—24 suoritetusta valtakunnan metsien arvioimisesta. Summary: The forests of Suomi (Finland). Results of the general survey of the forest of the country carried out during the years 1921—24. *Metsäntutkimuslaitoksen julkaisuja* 11: 1—421. Helsinki.

—»— 1948. *Pystypuiden kuutioimis- ja kasvunlaskentataulukot.* Helsinki.

—»— 1956. Suomen metsät vuosista 1921—24 vuosiin 1951—53. Kolmeen valtakunnan metsien inventointiin perustuva tutkimus. Summary: The forests of Finland and their development from 1921—24 to 1951—53. A survey based on three National Forest Inventories. *Metsäntutkimuslaitoksen julkaisuja* 47.1: 1—227. Helsinki.

Johnston, D. R., A. J. Grayson and R. T. Bradley, 1967. *Forest planning.* Faber and Faber Limited. London.

Kendall, R. H. and L. Sayn—Wittgenstein. 1961. A test of the effectiveness of air photo stratification. *Forestry Chronicle* 37.4: 350—355. Toronto.

Knox, R. L. 1956. Forest inventory for management of State Lands in Minnesota. *Journal of Forestry* 54. 2: 123—129. Washington D. C.

Kuittinen, R. 1971. Analyyttinen tulkintamalli. *Insinöörijärjestöjen Koulutuskeskus* 2.4: 1—6. Helsinki.

Kuusela, K. and S. Ervasti. 1969. Reliability comparisons of growing stock, increment and drain estimates in Finland in 1953—1966. *Metsäntutkimuslaitoksen julkaisuja* 68.3: 1—32. Helsinki.

Kuusela, K. and S. Poso. 1970. Satellite pictures in the estimation of the growing stock over extensive areas. *The Photogrammetric Journal of Finland* 4.1: 3—9. Helsinki.

Kuusela, K. and S. Salminen. 1969. The 5th national forest inventory in Finland. General desing, instructions for field work and data processing. *Metsäntutkimuslaitoksen julkaisuja* 69.4: 1—72. Helsinki.

Kuusela, K. and A. Salovaara. 1971. Kainuun, Pohjois-Pohjanmaan, Koillis-Suomen ja Lapin metsävarat vuosina 1969—1970. Summary: Forest resources in the Forestry Board Districts of Kainuu, Pohjois-Pohjanmaa, Koillis-Suomi and Lappi in 1969—1970. *Folia Forestalia* 110: 1—49. Helsinki.

Lackner, H. 1966. Vergleich von 9 Film-Masstabskombinationen für die Holzarten — Interpretation. *Mitteilungen der forstlichen Bundes-Versuchsanstalt* 72: 1—42. Vienna.

Langsaeter, A. 1926. Om beregning av middelfeilen ved regelmessige linjetakseringer. *Meddelelser fra det Norske Skogsforsøkvesen.* 2.7: 5—47. Oslo.

Langley, P. G. 1962. Aerial photo interpretation manual for the integrated forest survey and timber management inventory in California. *Pacific Southwest Forest and Range Experiment Station.* Berkeley.

Lauer, D. T. 1967. The feasibility of identifying forest species and delineating major timber types in California by means of high-altitude multispectral imagery. *Annual Progress Report to Nasa on Remote Sensing Application in Forestry.* Berkeley.

—»— 1968. Remote sensing applications in forestry. Forest species identification and timber type delineation on multispectral photography. *Annual Progress Report to Nasa on Remote Sensing Application in Forestry.* Berkeley.

Lindeberg, J. W. 1924. Über die Berechnung des Mittelfehlers des Resultates einer Linientaxierung. *Acta Forestalia Fennica* 25: 1—22. Helsinki.

—»— 1926. Zur Theorie der Linientaxierung. *Acta Forestalia Fennica* 31: 1—9. Helsinki.

Loetsch, F. 1957. A forest inventory in Thailand. *Unasylva* 11.4: 174—180. Rome.

—»— 1963. Die Waldinventur und ihre Bedeutung für Forstpolitik. Betriebswirtschaft und Waldbau. *Silva Fennica* 112.2: 1—34. Helsinki.

Loetsch, F. and K. E. Haller. 1964. *Forest inventory.* Vol. 1. Munich.

MacLean, C. D. 1963. Improving forest inventory area statistics through supplementary photo interpretation. *Journal of Forestry* 61.7: 512—516. Washington D.C.

Matérn, B. 1947. Metoder att uppskatta noggrannheten vid linje- och provytetaxering. Resumé: Methods of estimating the accuracy of line and sample plot surveys. *Meddelanden från Statens Skogsforskningsinstitut,* 36.1: 1—36. Stockholm.

—»— 1960. Spatial variation. Stockhastic models and their application to some problems in forest surveys and other sampling investigations. Sammanfattning : Stokastika modeller och deras tillämpning på några problem i skogstaxering och andra sampling undersökningar. *Meddelanden från Statens Skogsforskningsinstitut* 49.5: 1—144. Stockholm.

Myllynen, T. ja J. Rajala. 1970. Ryhmittely p-mediaanin ja klusterianalyysin avulla. *Yhdyskuntasuunnittelu* 1970, 4: 33—37. Helsinki.

Näslund, M. 1930. Om medelfelets beräkning vid linjetaxering. Summary: On computing the standard error in line-survey. *Svenska Skogsvårdsföreningens Tidskrift* 309—342. Stockholm.

Nersten, S. 1965. Avkastningsprognoser i skogsbruket II. Summary: Yield forecasts in forestry II. *Meldinger fra Institutt for Skogtaksasjon Norges Landbrukshøgskole* 73.4: 141—172. Vollebekk.

Neyman, J. 1938. Contribution to the theory of sampling human populations. *Jour. Amer. Stat. Assoc.,* 33: 101—116.

Nyyssönen, A. 1954. Kuutiomäärän arvioiminen relaskoopin avulla. Summary: Estimation of stand volume by means of the relascope. *Metsäntutkimuslaitoksen julkaisuja* 44.6: 1—31. Helsinki.

—»— 1955. On the estimation of the growing stock from aerial photographs. Seloste: Puuston arvioimisesta ilmakuvien avulla. *Metsäntutkimuslaitoksen julkaisuja* 46.1: 1—57. Helsinki.

—»— 1962. The use of aerial photography in inventories of tropical forests. *Publication of the Finnish Society of Photogrammetry* 3: 1—4. Helsinki.

—»— 1967. Remeasured sample plots in forest inventory. *Meddelelser fra Det Norkse Skogforsøksvesen* 84.22: 193—220. Vollebekk.

Nyyssönen, A. and P. Kilkki. 1966. Estimation of strata areas in forest survey. *Acta Forestalia Fennica* 81.3: 1—27. Helsinki.

Nyyssönen, A., P. Kilkki and E. Mikkola, 1967. On the precision of some methods of forest inventory. *Acta Forestalia Fennica* 81.4: 1—60. Helsinki.

Nyyssönen, A. and S. Poso. 1962. Koe metsikköluokitusten suorittamiseksi ilmakuvien avulla. Summary: Tree stand classification from aerial photographs: an experiment. *Silva Fennica* 112.3: 1—16. Helsinki.

Nyyssönen, A., S. Poso and C. Keil. 1968. The use of aerial photographs in the estimation of some forest characteristics. Seloste: Ilmakuvien käyttö eräiden metsän tunnusten arvioimisessa. *Acta Forestalia Fennica* 82.4: 1—35. Helsinki.

Nyyssönen, A., P. Roiko-Jokela and P. Kilkki. 1971. Studies on improvement of the efficiency of systematic sampling in forest inventory. Seloste: Systemaattiseen otantaan perustuvan metsän inventoinnin tehokkuudesta. *Acta Forestalia Fennica* 116: 1—26. Helsinki.

Nyyssönen, A. and Y. Vuokila. 1963. The effect of stratification on the number of sample plots of different sizes. *Acta Forestalia Fennica* 75.2: 1—17 Helsinki.

Palo, M. 1971. A systems-oriented frame model for planning research projects in forestry. Tiivistelmä: Metsällisen tutkimusprojektin suunnittelun systeemiteoreettinen kehysmalli. *Metsäntutkimuslaitoksen julkaisuja* 72.4: 1—60. Helsinki.

Payandeh, B. 1970. Relative efficiency of two-dimensional systematic sampling. *Forest Science* 16.3: 271—276. Washington D.C.

Pope, R. B. 1957. The effect of photo scale on the accuracy of forestry measurements. *Photogrammetric Engineering* 23.5: 869—873. Menasha.

Poso, S., C. Keil and T. Honkanen. 1968. Comparison of film-scale combinations in examining some stand characteristics from aerial photographs. Seloste: Eri filmimittakaavayhdistelmät eräiden metsikkötunnusten ilmakuvatulkinnassa. *Folia Forestalia* 53: 1—22. Helsinki.

Poso, S. and M. Kujala. 1971. Ryhmitetty ilmakuva- ja maasto-otanta Inarin, Utsjoen ja Enontekiön metsien inventoinnissa. Summary: Groupwise sampling based on photo and field plots in forest inventory of Inari, Utsjoki and Enontekiö. *Folia Forestalia* 132: 1—40. Helsinki.

Rogers, E. J. 1959. Proposed forest survey applying aerial photographs in regression technique. *Photogrammetric Engineering* 25.3: 443—445. Menasha.

—»— 1960. Forest survey design applying aerial photographs and regression technique for the Caspian forest of Iran. *Photogrammetric Engineering* 26. 3: 441—443. Menasha.

—»— 1961. Application of aerial photographs and regression technique for surveying Caspian forests of Iran. *Photogrammetric Engineering* 27.5: 811—816. Menasha.

Sandberg, B. 1961. Något om noggrannheten av virkesförråds- och bonitetsbestämningar vid okulärbedömning i fält och vid tolkning av flygbilder. *Nämnden för skoglig fotogrammetri* 16: 1—17. Stockholm.

—»— 1963. Provytetaxering i flygbilder med jämförande fältkontroll. *Nämden för skoglig fotogrammetri* 21: 1—34. Stockholm.

Sayn-Wittgenstein, L. and A. H. Aldred. 1967. Tree volumes from large-scale photos. *Photogrammetric Engineering* 33.1: 69—73. Menasha.

Schumacher, F. X. and R. A. Chapman. 1942. *Sampling methods in forestry and range management.* Duke University, Durham.

Seely, H. E. 1961. Some investigations of forest sampling methods. *Department of Forestry.* Technical Note No. 111: 1—17. Ottawa.

—»— 1964. Canadian forest inventory methods. *Department of Forestry.* Publication No. 1068: 1—11. Ottawa.

Seppälä, R. 1971. Linked systematic cluster sampling for the estimation of timber removals. *Metsäntutkimuslaitoksen julkaisuja* 72.3: 1—93. Helsinki.

Smith, J. H. G., Y. Lee and J. Dobie. 1960. Intensive assessment of factors influencing photo-cruising shows that local expressions of photo volume are best. *Photogrammetric Engineering* 26.3: 463—469. Menasha.

Smith, J. H. G., and D. Bajzak. 1961. Photo interpretation provides a good estimate of site index fir, hemlock, and cedar. *Journal of Forestry* 59.4: 261—263. Washington D.C.

Sorjonen, S. and J. Hakkarainen. 1971. *Valokuvauksen luennot.* Mimeograph. Helsinki.

Spiegel, M. R. 1961. *Theory and problems of statistics.* Schaum Publishing Co. New York.

Törnström, I. 1960. Vissa erfarenheter av flygbilder i samband med enklare skogsuppskattningar. *Nämnden för skoglig fotogrammetri* 14: 1—20. Stockholm.

Ware, K. D. and T. Cunia. 1962. Continuous forest inventory with partial replacement of samples. *Forest Science 4. Monograph* 3: 1—40. Washington D.C.

Welch, R. 1968. Film transparencies vs paper prints. *Photogrammetric Engineering* 24.5: 490—501. Menasha.

Young, H. E., F. M. Call and T. C. Tryon. 1963. Multimillion acre forest inventories based on airphotos. *Photogrammetric Engineering* 29. 4: 641—644. Menasha.

SELOSTE

Ilmakuva- ja maasto-otokseen perustuva metsän inventointimenetelmä

Johdanto

Inventointimenetelmä on tässä ymmärretty niiden työvaiheiden kokonaisuudeksi, joita tarvitaan metsäaluetta koskevien tietojen saamiseksi metsätaloudellista suunnittelua ja päätöksentekoa varten. Menetelmään vaikuttavat mm. tavoitteiden asettelu, metsäalueen laajuus ja merkitys, henkilökunnan ammattitaito ja saatavissa olevat tekniset apuvälineet.

Ilmakuvista pystytään usein tekemään melko pitkälle meneviä päätelmiä yksittäisten kohteiden puusto- ja kasvupaikkatunnuksista, kuten monet tutkijat ovat todenneet. Metsien inventointitehtäviin kuvatulkinta ei tavallisesti ole riittävän luotettavaa sellaisenaan. Kuvatulkinnalla voidaan kuitenkin vähentää tarvittavan maastotyön määrää. Kysymykseen tulevat tilastoteoreettisesti harhattomat menetelmät perustuvat kaksi- tai useampivaiheiseen otantaan. Kaksivaiheisessa otannassa tavallisin menettely on ollut, että ilmakuviin paikallistetaan suuri määrä koealoja, jotka kuvatulkinnalla osoitetaan esim. kuutiomäärän ja kasvupaikan perusteella ennen tulkinnan suorittamista määritettyihin osiin. Koealojen lukumäärien jakautumista saadaan osien osuusestimaatit w_k, joissa k on osan indeksi. Osien sisäisten tunnusten (esim. keskikuutiomäärien $\bar{y}_k$) määrittämiseksi valitaan jokaisesta osasta yleensä vähintään 2 koealaa mitattaviksi maastossa. Tutkittavan populaation keskiarvon estimaattoriksi saadaan (vrt. COCHRAN 1963, s. 328):

$$\bar{y}_{st} = \sum_{k}^{m} w_k \bar{y}_k$$

jossa m = osien lukumäärä.

Edellä kuvattua menetelmää kutsutaan ositetuksi kaksivaiheiseksi otannaksi (double sampling for stratification). Sitä on käytetty ja käytetään yhä runsaasti Pohjois-Amerikassa ja trooppisissa maissa (vrt. HILDEBRANDT 1962; NYYSSÖNEN 1962). Menetelmän esitti ensiksi NEYMAN (1938), ja sen toi metsätalouteen BICKFORD (vrt. B. 1952). Hänen käytössään menetelmä on osoittautunut selvästi yksivaiheisia, pelkkään maastotyöhön perustuvia paremmaksi. Hän esittää (1961), että USA:n koillisosien metsien inventoinnissa varta vasten suoritettava ilmakuvauskin voi kannattaa suorittaa, ellei kuvia ole muuten saatavissa.

Kaikki kyseessä olevaa menetelmää tutkineet eivät kuitenkaan ole päätyneet yhtäläisiin tuloksiin. Tämä johtunee siitä, että menetelmien soveltamisolosuhteet eri alueilla vaihtelevat, ja ennen kaikkea siitä, että myös inventoinneille asetetut tavoitteet vaihtelevat. Epäileviä kannanottoja menetelmän käyttökelpoisuudesta muualla ovat esittäneet mm. KENDALL ja SAYN-WITTGENSTEIN (1961); GROSSMANN ja WOLFF (1963); LOETSCH (1963);

NYYSSÖNEN, POSO ja KEIL (1968). Yleensä on tultu siihen tulokseen, että menetelmä on puhtaita maastomenetelmiä parempi inventoitavan alueen kokonaiskuutiomäärän ja maaluokkien selvittelyssä. Pyrittäessä yksityiskohtaisempien tunnusten (esim. kehitysluokkien osuuksien ja keskikuutioiden) estimointiin pelkkiin maasto-otantoihin perustuvat menetelmät ovat usein antaneet parhaita tuloksia.

Suomessa ja muissa Pohjoismaissa kaksivaiheisten otantamenetelmien käyttö on ollut vähäistä. Kiinnostus niitä kohtaan on kuitenkin nopeasti lisääntymässä. Tähän vaikuttavat toisaalta palkkakustannuksissa tapahtuva jatkuva nousu, mikä suosii menetelmiä, jotka eivät vaadi runsaasti maastotyötä, ja toisaalta ilmakuvien tulkintateknillisessä laadussa ja yleensä ilmakuvauksessa ja kuvatulkinnassa tapahtuva kehitys.

Tämän tutkimuksen lähtökohtana oli oletus, että ositettujen kaksivaiheisten otantamenetelmien laskennallista joustavuutta ja tehokkuutta voidaan kehittää. Edellinen ominaisuus kuvaa mahdollisuutta laskea joustavasti tuloksia mielivaltaisille luokille. Tehokkuus taas ilmoitetaan tulosten tarkkuuden suhteena inventoinnin kokonaiskustannuksiin. Kehittelyn tuloksena syntyi uudentyyppinen inventointimenetelmä, jolle annettiin nimeksi erään työvaiheen mukaan *ryhmitysmenetelmä*.

Tutkimuksen tavoitteiksi asetettiin ryhmitysmenetelmän kuvaus sekä menetelmän testaus lähinnä valtakunnan metsien inventointiin soveltamisen kannalta. Lisäksi pyrkimyksenä oli testitulosten perusteella löytää viitteitä inventointimenetelmien kehittämiselle entistä paremmin muuttuvia olosuhteita vastaaviksi.

Ryhmitysmenetelmän kuvaus

Ryhmitysmenetelmä voidaan käsittää erikoistapaukseksi ositetusta kaksivaiheisesta otannasta. Ensimmäisessä vaiheessa ilmakuviin paikallistetaan huomattavan suuri määrä otosyksiköitä, jotka tulkitaan. Otosyksiköt oletetaan koealoiksi. Ne sijoitetaan systemaattisesti yli koko alueen. Koealojen tulkinta ilmakuvista tapahtuu ilman erityisiä rajoja niin hienojakoista mitta-asteikkoa käyttäen kuin tulkinnan tarkkuus ja inventoinnin tavoitteet antavat aiheen. Toisessa vaiheessa osa ilmakuvista tulkituista koealoista mitataan maastossa. Näiden koealojen valitsemiseksi ilmakuvakoealoista muodostetaan mahdollisimman homogeenisia ryhmiä kaikkien ilmakuvista tulkittujen tunnusten suhteen. Jokaisesta ryhmästä valitaan yksi koeala esim. satunnaisotannalla mitattavaksi maastossa. Täten maastokoealojen ja ryhmien lukumäärät ovat yhtä suuret (ks. kuva 2233.1, s. 28).

Jokaiselle maastossa mitatulle koealalle lasketaan täydellisesti eritellyt tulokset. Nämä siirretään sellaisinaan kaikille samaan ryhmään kuuluville ilmakuvakoealoille (ks. kuva 2233.1). Kun siirto on suoritettu kaikkien ryhmien osalta, jokaiselle ilmakuvakoealalle saadaan tulokseksi muodollisesti täydelliset tiedot. Jokainen ilmakuvakoeala voi siten muodostaa laskennallisen käsittely-yksikön, mikä tekee menetelmästä laskennallisesti erittäin joustavan. Ryhmitysmenetelmän ja normaalin ositetun kaksivaiheisen otannan välisiä eroja ja yhtäläisyyksiä on esitetty kuvassa 21.1 (s. 00).

Siirtämällä maastotiedot ilmakuvakoealoille ja käyttämällä näitä koealoja itsenäisinä tulostuslaskennan yksikköinä päästään siihen, että jokaisella yksiköllä on sama paino. Jos ilmakuvakoealaojen lukumäärää merkitään n:llä, tutkittavaa ositetta j:llä ja tutkittavalle luokalle sattuneitten ilmakuvakoealojen lukumäärää n_j:llä, luokan j osuusestimaattoriksi saadaan:

$$p_j = n_j/n$$

Vastaavasti luokan j keskiarvoestimaatti saadaan yhtälöllä:

$$\bar{y}_j = \sum_i y_{ji}/n_j$$

jossa

y_{ji} = tutkittavan tunnuksen y arvo koealalla i, joka kuuluu luokkaan j.

Varianssien estimointiyhtälöiden kehittelyssä käytettiin hyväksi ositetulle kaksivaiheiselle otannalle johdettuja yhtälöitä. Niiden suora soveltaminen ei käynyt päinsä, koska ryhmitysmenetelmässä jokaisesta ryhmästä valitaan ainoastaan yksi maastokoeala, jonka perusteella varianssin estimointi yksittäiselle ryhmälle ei ole mahdollista. Tämän johdosta varianssien estimointi perustettiin ryhmäyhdistelmien muodostamiseen. Estimoinnissa oletettiin, että ryhmien sisäiset varianssit ovat ryhmäyhdistelmittäin yhtä suuret. Ryhmäyhdistelmät muodostetaan erikseen jokaisen tunnuksen varianssin estimointia varten. Samaan ryhmäyhdistelmään kuuluvien maastokoealojen perusteella estimoidaan ryhmäyhdistelmän sisäinen varianssi. Se oletetaan yhtä suureksi kuin ryhmäyhdistelmään kuuluvien ryhmien sisäiset varianssit.

Pinta-alaluokan osuuden varianssin estimoimiseksi samaan ryhmäyhdistelmään pannaan ne ryhmät, joilla ilmakuvista tulkittujen tunnusten perusteella näyttää olevan yhtä suuret mahdollisuudet olla tai olla olematta tutkittavaa luokkaa. Estimaattoriksi saatiin

$$v_p \simeq \sum_{k'}^{m'} \frac{w_{k'}{}^2 p_{k'} q_{k'}}{m_{k'}-1} + g \sum_{k'}^{m'} \frac{w_{k'}(p_{k'}-p)^2}{m}$$

jossa

m' = ryhmäyhdistelmien lukumäärä
$w_{k'}$ = ryhmäyhdistelmän k' osuusestimaatti
$p_{k'}$ = tutkittavan luokan osuus ryhmäyhdistelmässä k' sitä koskevien maastohavaintojen perusteella
$q_{k'}$ = $1 - p_{k'}$
$m_{k'}$ = maastokoealojen lukumäärä ryhmäyhdistelmässä k'
n = ilmakuvakoealojen lukumäärä
p = tutkittavan pinta-alaluokan osuuden otosestimaatti
g = ilmakuvakoealojen systemaattisesta paikallistamisesta aiheutuva korjauskerroin

Termien *ryhmien sisäinen* ja *ryhmien välinen varianssi* määrittämiseksi edellinen yhtälö kirjoitetaan muotoon:

$$v_p = \frac{v_1}{m} + g\,\frac{v_2}{n}$$

jossa

v_1 = ryhmien sisäinen varianssi (ks. yhtälö 2234.4, s. 31) ja
v_2 = ryhmien välinen varianssi (ks. yhtälö 2234.5, s. 31).

Korjauskertoimen g mukaanotto yhtälöön on perusteltua, koska ilmakuvakoealat paikallistetaan systemaattisesti eikä arvontaan perustuen. Tällöin on todennäköistä, että systemaattisesti paikallistettu otos edustaa tutkittavaa populaatiota paremmin kuin jos otos olisi paikallistettu arpomalla. Tämän johdosta g on tavallisesti ykköstä pienempi. Jos ilmakuvakoealojen edustamien neliöiden (ks. kuva 2234.1, s. 32) keskimääräistä sisäistä varianssia merkitään σ^2_{st} ja koko alueen satunnaisotannalla saatavaa vastaavaa varianssia σ^2_r, voidaan g:n arvo määritellä:

$$g = \sigma_{st}^2 / \sigma_r^2$$

Kertoimen g arvo voidaan ajatella estimoitavan ylimääräisen ilmakuva-aineiston perusteella. Ylimääräisten ilmakuvista tulkittujen koealojen perusteella voidaan tarvittavalle määrälle neliöitä laskea sisäiset varianssit. Niiden keskiarvon suhde koko aineistosta saatavaan, satunnaisotannan edellyttämään varianssiin antaa kysymyksessä olevan estimaatin.

Keskiarvojen varianssien estimointi samalla periaatteella kuin edellä esitettiin pinta-alaluokkien osuuksille (ks. yhtälöt 2234.8—2234.11, s. 33—34) tullee vain harvoin kysymykseen. Tämä johtuu siitä, että homogeenisten ryhmäyhdistelmien muodostaminen sekä pinta-alaluokan että tutkittavan kvantitatiivisen tunnuksen, esim. kuutiomäärän, suhteen on usein ylivoimainen tehtävä. Tämän takia tässä on suositeltu ryhmäyhdistelmien muodostamista homogeenisiksi ainoastaan pinta-alaluokkien suhteen. Ryhmien sisäiset varianssit tulevat estimoitaviksi ryhmäyhdistelmittäin regressiosuorien avulla. Menettelyä varten valitaan ilmakuvista tulkituista tunnuksista se, joka parhaiten korreloi tutkittavan tunnuksen kanssa. Merkitään sitä x:llä, kun taas tutkittavaa tunnusta merkitään y:llä. Ryhmäyhdistelmien maastokoealojen ja niitä vastaavien ilmakuvakoealojen mukaiset tasopisteet, x,y -pisteet, tasoitetaan regressiosuoralla. Tällöin ryhmien sisäisen varianssin estimaattoriksi saadaan

$$v_1 = m \sum_{k'}^{m'} w_{k'}^2 \frac{s_{y \cdot xk'}^2}{m_{k'}}$$

jossa $s_{y.xk'}^2$ saadaan estimaattorilla 2234.13 (s. 34), jossa $b_{k'}$ on regressiokerroin ryhmäyhdistelmässä k', kun regressio on muotoa $y = a + bx$.

Edellinen yhtälö edellyttää, että ryhmät ovat homogeenisia tutkittavan tunnuksen suhteen. Mikäli tämä ei pidä paikkaansa, on ryhmien sisäisen varianssin estimoinnissa paras käyttää estimaattoria 2234.14, jossa yksittäisten ryhmien x-havaintojen varianssit lisäävät ryhmien sisäistä varianssia. Ryhmien välisten varianssien estimointiin tulee soveltaa estimaattoreita 2234.15 tai 2234.16 (s. 36). Edellistä sovelletaan, jos v_1 estimoidaan yhtälöllä 2234.12 ja jälkimmäistä, jos v_1 estimoidaan yhtälöllä 2234.14. Ilmakuvakoealojen systemaattisesta paikallistamisesta aiheutuva korjauskerroin estimoidaan samojen periaatteiden mukaisesti kuin pinta-alaluokkien varianssien yhteydessä on esitetty.

Testiaineistot

Aineistojen keruu keskitettiin pääosaltaan Suonenjoen kauppalan alueelle kuudelle valtakunnan viidennen metsien inventoinnin arvioimislohkolle (kuva 311.1, s. 37). Aineistojen keruu suoritettiin vuosina 1967 (kuva 311.2, s. 38) ja 1968 (kuva 311.3, s. 38). Edellisen vuoden aineistoon tuli yhteensä 1536 ja jälkimmäisen 2612 relaskooppikoealaa. Koealojen määrittämisessä ja mittauksessa käytettiin läpimitta / etäisyys -suhdetta 1: 50, jolloin yksi luettu puu vastasi pohjapinta-alaa 1 m²/ha.

Kaksi henkilöä suoritti koealojen tulkinnan ilmakuvista. Heistä toinen, metsätieteiden ylioppilas, tulkitsi kaikki koealat tutkimusalueen välittömässä läheisyydessä käymättä silti tutkimuskohteissa. Täten hänellä oli hyvä yleiskuva alueen metsistä. Toinen tulkki, valtakunnan metsien inventoinnin ryhmänjohtaja ja metsänhoitaja, tulkitsi vain vuoden 1967 aineiston 1536 koealaa käymättä tutkimusalueella tai sen läheisyydessä.

Tulkinta suoritettiin maanmittaushallituksen vuonna 1966 suorittamasta 1: 22 000 ku-

vauksesta tilattuja pintakopioita käyttäen (ks. kuva 32.1, s. 44). Kopiot valmistettiin kiiltävä-pintaiselle paperille. Koealapaikat merkittiin ilmakuviin vuoden 1967 aineiston osalta irrallisin kaavioin, jotka kiinnitettiin kuvien päälle teipillä. Menettelyn haittana oli, että lämpö- ja kosteusolojen vaihdellessa ilmakuvat »elivät», josta aiheutui koealojen paikan siirtymistä. Vuoden 1968 aineistossa tätä haittaa ei ollut, koska koealapisteet valokuvattiin suoraan ilmakuville niiden kehitysvaiheessa.

Koealoilta tulkitut tunnukset ovat nähtävissä tulkinta-asteikkoineen taulukossa 32.1 (s. 45). Koealan sattuessa kuvioiden rajalle se voitiin jakaa osiin ehdolla, että kuvioiden osuuksien summa tuli aina 1.0:ksi (ks. kuva 312.2, s. 41). Täten yhtä koealaa kohti saattoi tulla useita tietueita (vrt. kuva 32.3, s. 47). Ryhmitystä varten nämä jouduttiin kuitenkin yhdistämään yhdeksi. Kuvatulkinnan tarkkuudesta maastomittausten suhteen antaa käsitystä kuva 32.2 (s. 46). Koealojen tarkkaa paikkaa määritettäessä otettiin huomioon säteettäissiirtymän vaikutus (ks. kuva 311.4, s. 39).

Maastotietojen keruussa jokaiselle koealalle tehtiin joko yksi tai, jos kysymyksessä oli jaettu koeala, useampia kuvionselityksiä valtakunnan metsien inventoinnin koodaussysteemiä käyttäen. Kaikista koealan puista mitattiin rinnankorkeusläpimitta sekä merkittiin muistiin puulaji. Vuoden 1967 aineistosta joka koealan 1., 5., 9., jne. puu (yht. 2 732 puuta) otettiin koepuuksi. Niistä mitattiin rinnankorkeusläpimitan lisäksi kantoläpimitta ja pituus sekä kairattiin läpimitan kasvu ja arvioitiin pituuskasvu. Puiden kapenemiskäyrät piirrettiin valtakunnan metsien inventoinnissa tutkimusalueelta ja sen ympäristöstä mitatun aineiston, noin 400 koepuuhavainnon, perusteella.

Jokaiselle maastokoealalle laskettiin täydelliset, tulostuslaskennassa tarvittavat tunnukset kuvioittain. Ne syötettiin magneettinauhoille, jolloin yhtä koealakuviota vastaavat tiedot muodostivat yhden tietueen (kuva 312.1, s. 40). Tulostuslaskennat suoritettiin Helsingin yliopiston tietokoneella. Maastotiedot poimittiin kullekin ryhmälle satunnaisotannalla.

Esitetyistä aineistoista muodostettiin yhteensä kuusi erillistä testiaineistoa (kuva 411.1 s. 48 ja taulukko 411.1, s. 50). Ilmakuvakoealojen ryhmitys suoritettiin lajittelukoneella. Tämän jälkeen maastokoealojen otanta suoritettiin jokaiselle testiaineistolle toistuvasti 20—30 kertaa. Jokaisen toisto-otoksen perusteella estimoitiin kaikki tutkittaviksi valitut parametrit. Tietyn parametrin eri toistoista saatujen estimaattien varianssista saatiin tunnus, johon vertaamalla oli mahdollista tehdä ryhmitysmenetelmän varianssiestimaattorien laatua koskevia päätelmiä. Toisto-otoksiin perustuvat varianssit laskettiin testiaineistoittain yhtälöllä

$$v_{\bar{y}h} = \sum_{i}^{n_{rh}} \frac{(\bar{y}_{hi} - \bar{y}_h)^2}{n_{rh} - 1}$$

jossa

n_{rh} = toistojen lukumäärä testiaineistossa h

$\bar{y}_{hi}$ = testiaineistosta h, otoksesta i laskettu keskiarvo

$$\bar{y}_h = \sum_{i}^{n_{rh}} \frac{\bar{y}_{hi}}{n_{rh}}$$

Testiaineistoittaisten tulosten vertaamiseksi varianssit muunnettiin maastokoealojen lukumäärästä riippumattomaan muotoon:

$$v_{yh} = m_h \, v_{\bar{y}h}$$

jossa

m_h = maastokoealojen lukumäärä aineistossa h

Koska testiaineistot eivät poikenneet luonteeltaan paljoa toisistaan (ks. liite 2), saatujen varianssien, v_{yh}, olisi pitänyt olla likimain yhtä suuret. Testiaineistoittaisten toistojen suhteellisen pienen lukumäärän (20—30 kpl) johdosta varianssien v_{yh} kesken esiintyi kuitenkin huomattavan suurta vaihtelua (ks. liite 2). Tästä vaihtelusta olisi myöhemmissä tarkasteluissa aiheutunut hankaluutta. Tämän välttämiseksi tehtiin oletus, että kaikkien kuuden testiaineiston todelliset varianssit V_{yh} ovat yhtä suuret. Tällöin varianssien estimointi voitiin perustaa kaikkiin testiaineistoista tehtyihin toisto-otoksiin (140 kpl):

$$v_y = \sum_h^{n_h} \frac{v_{yh}}{n_h}$$

jossa

n_h = testiaineistojen lukumäärä = 6

Edellä esitetystä keskiarvovarianssista päästiin takaisin aineistokohtaisiin, tasoitettuihin variansseihin yhtälöllä:

$$v'_{\bar{y}h} = v_y / m_h$$

Ryhmitysmenetelmä varianssien estimoinnissa

Varianssien estimointi esitettiin (s. 117) suoritettavaksi pinta-alaositteen osuuden osalta yhtälöllä $v_p = v_1/m + g\, v_2/n$. Keskikuution vastaava varianssiestimaatti saadaan, kun v_p korvataan v_y:lla (yhtälö 2234.9, s. 34). Suurin merkitys varianssin muodostumisessa on yhtälön ensimmäisellä termillä v_1/m. Sen osuus on arviolta 80—95 %. Tämän takia ja koska toisto-otoksista laskettuihin variansseihin ei sisältynyt ryhmien välisen varianssin vaikutusta, ryhmitysmenetelmän varianssiestimaattorien tarkastelu rajoitettiin ainostaan ryhmien sisäiseen varianssiin.

Ryhmitysmenetelmän varianssiestimaattorit antoivat testeissä oikean suuruisia tuloksia kaikkien pinta-alaluokkien osuuksien ja koko alueelle lasketun keskikuution varianssien estimoinnissa (taulukko 4142.1, sarakkeet 5 ja 7, s. 57, ja taulukko 4143,1, rivi 1, sarakkeet 4 ja 7, s. 58).

Koko aluetta pienempien pinta-alaluokkien keskikuutioille estimaattorit antoivat aliarvoja niissä tapauksissa, joissa keskiarvo ja vastaavia pinta-alaluokkia ei kyetty tulkitsemaan ilmakuvilta täysin yhdenmukaisesti maastotulkintojen kanssa. Tähän johtavia syitä on havainnollistettu kuvassa 413.1 (s. 52). Siinä pienellä ympyrällä varustetut pisteet kuuluvat tutkittavaan luokkaan ja ristillä merkityt pisteet on valittu eri ryhmistä (yht. 15 kpl) mitattaviksi maastossa. Kuvassa luokan keskikuutio saadaan huomattavasti liian suureksi, koska (a) luokasta valitut maastokoealat sattuvat akselistossa liian oikealle ja (b) maastokoealat sattuvat myös regressiosuoran yläpuolelle. Ryhmitysmenetelmän varianssiestimaattorit ottavat huomioon vain jälkimmäisenä esitetyn virhelähteen.

Taulukosta 4143.1 (s. 58, sarakkeet 4 ja 7) on todettavissa, kuinka paljon metsämaan (rivi 2) ja sitä pienempien luokkien (rivit 3 ja 4) keskikuutioiden varianssit tulivat aliarvioiduiksi. Kasvupaikka- ja kehitysluokkien keskikuutioiden kohdalla yksinkertaisen satun-

naisotannan yhtälöillä olisi päästy luotettavampaan varianssiestimaattiin kuin ryhmitysmenetelmälle esitetyillä estimaattoreilla. Ilmakuvista epäluotettavasti tulkittavissa olevien pinta-alaluokkien keskikuutioiden varianssien estimointiongelmaa on tutkittu yksityiskohtaisemmin metsämaan osalta. Kehitetyllä oikaisumenetelmällä saadut tulokset (taulukko 4143.2, s. 61) osoittautuivat tutkitussa tapauksessa oikean suuruisiksi. Kehitettyä menettelyä ei voida kuitenkaan pitää yleisratkaisuna eikä se sovellu lainkaan metsämaan sisäisten pinta-alaluokkien keskikuutioiden varianssin estimoimiseen.

Eri menetelmien tehokkuuden vertailu

Eräs ryhmitysmenetelmän kehittämisen tavoite oli tehokkuudeltaan ositettua kaksivaiheista otantaa parempi menetelmä. Samankaltaisuutensa vuoksi ryhmitysmenetelmän ja ositetun kaksivaiheisen otannan tehokkuuden vertailu voitiin tehdä suoraan toisto-otoksista saatujen varianssien perusteella.

Ositettua kaksivaiheista otantaa sovellettiin kahdella ositekoolla. Toisessa sovellutuksessa (Strat. a) ositteet olivat noin 13 kertaa ryhmien kokoa suuremmat ja toisessa (Strat. b) vain 2 kertaa suuremmat. Vertailussa käytetyt aineistot on esitetty taulukossa 42.1 (s. 65), jossa lisämenetelmänä on myös yksinkertainen satunnaisotanta. Vertailuaineistoista lasketut varianssit on esitetty taulukossa 52.1 (s. 70).

Toinen ryhmitysmenetelmän tärkeä vertailukohde oli systemaattinen, pelkästään maastokoealoihin perustuva otanta. Tehokkuuksien vertailu menetelmien kesken suoritettiin satunnaisotannan välityksellä seuraavan yhtälön osoittamalla perusteella:

$$\frac{\text{Ryhmitysmenetelmän tehokkuus}}{\text{Satunnaisotannan tehokkuus}} : \frac{\text{Systemaattisen otannan tehokkuus}}{\text{Satunnaisotannan tehokkuus}} = \frac{\text{Ryhmitysmenetelmän tehokkuus}}{\text{Systemaattisen otannan tehokkuus}}$$

Systemaattisen ja satunnaisotannan tehokkuussuhteet eri tunnusten estimoinnissa saatiin vastaavien varianssisuhteiden käänteisarvoina olettaen, että vertailtavissa menetelmissä sovellettiin yhtä suuria maastokoealojen lukumääriä. Varianssisuhteiden estimoinnissa käytettiin saman tyyppistä menettelyä kuin kertoimen g yhteydessä kaavailtiin käytettävän (ks. s. 31). Systemaattisessa otannassa jokainen koeala edusti tiettyä neliönmuotoista aluetta (ks. kuva 2234.1, s. 32). Se voitiin käsittää ositteeksi, josta kyseinen koeala oli valittu. Kun oletettiin, että kyseinen koeala oli valittu neliöstä satunnaisotannalla, koealan havaintoarvon edustavuus voitiin katsoa kyseisen neliön sisäisen varianssin mukaiseksi. Tämän perusteella systemaattisen ja satunnaisotannan varianssien suhde saatiin neliöiden keskimääräisen sisäisen varianssin ja inventointialueen kokonaisvarianssin suhteena.

Systemaattisen ja satunnaisotannan varianssisuhteiden tutkimiseen käytettiin vuoden 1968 aineiston arvioimislohkojen 1, 4, 5 ja 6 koealoja (kuva 311.3, s. 38). Oletettujen erikokoisten neliöiden sisäiset varianssit estimoitiin linjalla olevien koealojen avulla kuten on esitetty kuvassa 44.1 (s. 67). Kolmelle tunnukselle lasketut varianssisuhteet on piirretty kuvaan 53.1 (s. 72) koealan edustaman pinta-alan funktiona.

Kuva 53.1 osoitti, että systemaattisen otannan tehokkuus satunnaisotannan suhteen lisääntyy, kun otannan intensiivisyys kasvaa. Tulos on sopusoinnussa NYYSSÖSEN, KILKIN ja MIKKOLAN (1967) saamien tulosten kanssa. Heidän tutkimuksessaan suurin koealan edus-

tama pinta-ala oli vain 9 ha, kun taas taulukossa 53.1 pienin pinta-ala oli 10 ha. Näille pinta-aloille saadut varianssisuhteet olivat likimain yhtä suuret.

Ryhmitysmenetelmän ja satunnaisotannan tehokkuussuhteen estimoiminen tehtiin useassa vaiheessa. Ensiksi laskettiin tutkittavien tunnusten varianssit vertailtavilla menetelmillä olettaen, että kummassakin menetelmässä maastokoealojen lukumäärät olivat yhtä suuret. Satunnaisotannan ja ryhmitysmenetelmän varianssien suhteet on esitetty taulukossa 541.2 (s. 76). Taulukon tuloksissa on mukana kaikki kuusi testiaineistoa omalla painollaan. Painotusmenettelyä havainnollistaa taulukon 541.1 yhteydessä annettu esimerkki (s. 75).

Ryhmitysmenetelmän ja satunnaisotannan tehokkuussuhteitten estimoimiseksi täytyi taulukon 541.2 (s. 76) varianssisuhteiden lisäksi ottaa huomioon seuraavat näkökohdat:

1) Ryhmitysmenetelmän varianssit, joihin taulukon 541.2 arvot perustuivat, eivät sisältäneet ilmakuvakoealojen edustavuusvarianssin vaikutusta (gv_2/n).

2) Samalla inventoinnin rahamäärällä pystytään mittaamaan useampia maastokoealoja satunnaisotannalla kuin ryhmitysmenetelmällä, koska jälkimmäisessä menetelmässä osa varoista menee ilmakuvamateriaalin hankintaan ja kuvatulkintaan.

3) Satunnaisotannan suuremmasta maastokoealamäärästä johtuen menetelmän edellyttämät kävelymatkat koealalta toiselle ovat keskimäärin lyhemmät. Tämän johdosta satunnaisotannassa maastokoealojen keskimääräiset yksikkökustannukset ovat pienemmät kuin ryhmitysmenetelmässä.

Edellä esitettyjen näkökohtien ottaminen huomioon edellytti tietoja ilmakuvien hankinnasta, kuvatulkinnasta ja maastotyöstä aiheutuvista kustannuksista. Ne pyrittiin saamaan mahdollisimman paljon todellisuutta vastaaviksi käytettävissä olevien kokemusten ja tietolähteitten avulla. Käsittelymahdollisuuksien laajentamiseksi oletettiin joukko erilaisia inventointitilanteita, joille menetelmien tehokkuussuhteet laskettiin. Ne on esitetty oletuksineen kuvassa 5422.1 (s. 79) ja liitteessä 3. Maastokoealojen kustannuksia koskeva oletus on esitetty kuvassa 5422.2 (s. 80). Ryhmitysmenetelmän tehokkuudet satunnaisotannan suhteen on esitetty taulukossa 543.1 (s. 85).

Sen jälkeen kun sekä ryhmitysmenetelmän että systemaattisen otannan tehokkuudet oli estimoitu satunnaisotannan suhteen, ryhmitysmenetelmän tehokkuus systemaattisen otannan suhteen oli helppo laskea (vrt. yhtälö s. 121). Tulokset on esitetty tunnuksittain ja inventointitilanteittain taulukossa 55.1 (s. 86).

Päätelmät

Suoritetuissa testeissä ja myöskin käytännössä suoritetuissa kokeiluissa (POSO & KUJALA 1971) ryhmitysmenetelmä osoittautui toimintakelpoiseksi kaikkien muiden parametrien paitsi ilmakuvista epävarmasti tulkittavien pinta-alaluokkien keskiarvojen varianssien estimoinnissa. Esitetyllä puutteella on kuitenkin verrattain vähäinen merkitys menetelmän käyttökelpoisuuteen ja sekin voitaneen poistaa lisätutkimuksella. Käytännön kannalta tärkeä havainto oli myös, että ilmakuville merkityt pisteet voitiin paikallistaa maastoon riittävällä nopeudella ja tarkkuudella.

Ryhmitysmenetelmää voidaan pitää ositettua kaksivaiheista otantaa edullisempana lähinnä sen selvästi paremman laskennallisen joustavuuden takia. Jos ositteiden koko on ryhmien kokoon verrattuna monta (esim. 10) kertaa suurempi, on ryhmitysmenetelmä jonkin verran ositettua kaksivaiheista otantaa parempi myös tehokkuudessa.

Ryhmitysmenetelmän vertaaminen systemaattiseen otantaan oli menetelmien suuren erilaisuuden johdosta hankalaa. Saadut tulokset antavat kuitenkin mahdollisuuden seuraaviin päätelmiin:

1) Ryhmitysmenetelmä on selvästi systemaattista otantaa tehokkaampi kokonaiskuutiomäärän ja maaluokkien osuuksien estimoinnissa.

2) Tehokkuudet metsämaan keskikuution estimoinnissa ovat likimain yhtä suuret. Metsämaan kokonaiskuution estimoinnissa ryhmitysmenetelmän tehokkuus on selvästi suurempi kuin metsämaan keskikuution estimoinnissa. Tämä johtuu siitä, että metsämaan osuuden ja keskikuution estimointivirheeet (virhesuunnat) ovat negatiivisessa korrelaatiossa toisiinsa.

3) Ryhmitysmenetelmän tehokkuus on selvästi systemaattisen otannan tehokkuutta heikompi pienten, epävarmasti tulkittavien pinta-alaluokkien ja niiden keskiarvojen (esim. kehitysluokkien osuuksien ja keskikuutioiden) estimoinnissa.

Yksiselitteisiä tuloksia ryhmitysmenetelmän ja systemaattisen otannan tehokkuussuhteista ei voida esittää, koska suhteiden suuruus riippuu hyvin monista tekijöistä, joista osaa voidaan pitää sattumanvaraisina. Tärkeimpien tekijöiden vaikutusta tehokkuuksien suhteisiin on analysoitu kuvissa 632.1—632.5 (s. 92—99).

Ryhmitysmenetelmä on tietojen keruun järjestelyn osalta systemaattista otantaa joustavampi. Ryhmitysmenetelmä antaa melko helpon mahdollisuuden maastotyön ja tulosten tarkkuuden säätelyyn kenttätyökauden aikana, kuten todettiin Perä-Lapin inventoinnissa. Tämä merkitsee, että ryhmitysmenetelmällä on helpompi päästä optimaalisena pidettävään tarkkuuteen ja siten säästää esim. »liikatarkkuudesta» aiheutuvia ylimääräisiä kustannuksia. Myös maastotöiden päivittäisessä järjestelyssä ryhmitysmenetelmä on todennäköisesti joustavampi. Työurakat voidaan kuvatulkinnalla suunnitella kohtuullisiksi etukäteen. Koealojen mittausjärjestys voidaan valita niin, että maastokulkua helpottavia reittejä voidaan käyttää tehokkaasti hyväksi ja vaikeita kulkuesteitä voidaan välttää.

Ryhmitysmenetelmän useissa tapauksissa suuri etu systemaattiseen otantaan nähden muodostuu mahdollisen vuotuisen työskentelyajan pitenemisestä. Mikäli inventointia on suorittamassa suurelta osalta pysyvä henkilökunta, koituu systemaattisen maasto-otannan välttämättömästä kausiluonteisuudesta haittaa. Ryhmitysmenetelmässä välitöntä inventointityötä voidaan suorittaa kuvatulkinnan muodossa myös silloin, kun luonnonolosuhteet eivät anna mahdollisuutta maastotyöhön.

Ryhmitysmenetelmän ja systemaattisen otannan vertailuissa voitiin todeta, että menetelmien edut ja haitat menevät monessa kohdin ristiin. Tämän takia olisi järkevää tutkia menetelmien yhdistelymahdollisuutta niin, että molempien menetelmien edut tulisivat mahdollisimman täydellisinä uuteen menetelmään ja haitat jäisivät mahdollisimman vähäisiksi. Lisäksi silloin, kun kysymys on jatkuvasti toistuvista inventoinneista, tulee harkittavaksi ns. pysyvien koealojen liittäminen osana uuteen menetelmään.

Appendix 1. Output of one sample of the grouping method (material 13, sample 8)

Liite 1. *Ryhmitysmenetelmän yhden otoksen tulostus (aineisto 13, otos 8)*

A. Area data — *Pinta-alatiedot*

Proportions of land-use classes, by land classes

Maaluokkien osuudet alaryhmittäin

Land-use class *Maaluokka*	Total area *Koko alue*		Mineral soils *Kankaat*		Spruce swamps *Korvet*		Pine swamps *Rämeet*	
	Plot — *Koealoja*		Plot — *Koealoja*		Plot — *Koealoja*		Plot — *Koealoja*	
	No. - *kpl*	%	No. - *kpl*	%	No. - *kpl*	%	No. - *kpl*	%
1	1 087,00	70,7	765,00	99,4	108,50	96,0	213,50	75,7
2	37,00	2,4	0,00	0,0	0,00	0,0	37,00	13,1
3	36,00	2,3	0,00	0,0	4,50	3,9	31,50	11,1
4	120,00	7,8	0,00	0,0	0,00	0,0	0,00	0,0
5	15,00	0,9	4,00	0,5	0,00	0,0	0,00	0,0
6	15,00	0,9	0,00	0,0	0,00	0,0	0,00	0,0
7	226,00	14,7	0,00	0,0	0,00	0,0	0,00	0,0
Total *Yhteensä*	1 536,00	100,0	769,00	100,0	113,00	100,0	282,00	100,0

Proportions of site-fertility classes on forest land

Kasvupaikkaluokkien osuudet metsämaalla

Site class *Kasvu-paikkal.*	Mineral soils *Kankaat*		Spruce swamps *Korvet*		Pine swamps *Rämeet*		Whole for.land *Koko metsäm.*	
	Plot — *Koealoja*		Plot — *Koealoja*		Plot — *Koealoja*		Plot — *Koealoja*	
	No. - *kpl*	%	No. - *kpl*	%	No. - *kpl*	%	No. - *kpl*	%
2	305,50	39,9	8,00	7,3	0,00	0,0	313,50	28,8
3	273,50	35,7	44,00	40,5	21,50	10,0	339,00	31,1
4	186,00	24,3	56,00	52,0	99,50	46,6	342,00	31,4
5	0,00	0,0	0,00	0,0	92,50	43,3	92,50	8,5
Total *Yhteensä*	765,00	100,0	108,50	100,0	213,50	100,0	1 087,00	100,0

Degree of stoniness, treatment classes, and age classes on forest land

Kivisyys, kehitysluokat ja ikäluokat metsämaalla

Class	Stoniness *Kivisyys*		Treatment class *Kehitysluokka*		Age class *Ikäluokka*	
	Plot — *Koealoja*		Plot — *Koealoja*		Plot — *Koealoja*	
	No. - *kpl*	%	No. - *kpl*	%	No. - *kpl*	%
0	0,00	0,0	0,00	0,0	35,00	3,2
1	130,00	11,9	35,00	3,2	22,50	2,0
2	564,00	51,8	100,10	9,2	21,00	1,9
3	9,00	0,8	47,50	4,3	75,10	6,9
4	62,00	5,7	213,50	19,6	125,50	11,5
5	86,50	7,3	178,00	16,3	117,50	10,8
6	30,50	2,8	174,40	16,0	154,00	14,1
7	142,50	13,1	49,00	4,5	92,00	8,4
8	62,50	5,7	289,50	26,6	286,40	26,3
9	0,00	0,0	0,00	0,0	85,00	7,8
10					41,00	3,7
11					32,00	2,9
Total *Yhteensä*	1 087,00	100,0	1 087,00	100,0	1 087,00	100,0

Appendix 1 (cont.)
Liite 1 (jatk.)

B. Growing-stock data — *Puustoa koskevat tunnukset*
Mean volumes by land-use classes and tree species
Keskikuutiot maaluokittain ja puulajeittain

Land-use class *Maaluokka*	Pine *Mänty*		Spruce *Kuusi*		Broad-leaved *Lehtipuu*		Total *Yhteensä*	
	m³/ha	%	m³/ha	%	m³/ha	%	m³/ha	%
1	27,32	28,3	50,34	52,2	18,66	19,3	96,32	100,0
2	2,91	75,0	0,00	0,0	0,97	25,0	3,89	100,0
3	1,11	100,0	0,00	0,0	0,00	0,0	1,11	100,0
1—3 total *1—3 yhteensä*	25,72	28,4	47,17	52,1	17,51	19,3	90,41	100,0
Whole area, total *Koko alue, yht.*	19,43	28,4	35,62	52,1	13,22	19,3	68,28	100,0

Mean volumes by site-fertitily classes on forest land
Keskikuutiot kasvupaikkaluokittain metsämaalla

Site-fert. class *Kasvup. lk.*	Mineral soils *Kankaat*		Spruce + pine swamps *Korvet + rämeet*		Total forest land *Koko metsämaa*	
	m³/ha	%	m³/ha	%	m³/ha	%
2	134,65	45,7	17,00	0,9	131,64	39,4
3	128,04	38,9	75,26	33,2	117,84	38,1
4	73,83	15,2	41,57	43,7	59,12	19,3
5	0,00	0,0	35,23	22,0	35,23	3,1
Total *Yhteensä*	117,50	100,0	45,99	100,0	96,32	100,0

Mean volumes, mean diameters, and mean increments on forest land
Keskikuutiot, keskiläpimitat ja keskikasvut metsämaalla

Treatment class *Kehitysluokka*	Mean volume *Keskikuutio*		Mean diameter *Keskiläpimitta* cm	Mean increment *Keskikasvu*	
	m³/ha	%		m³/ha	%
1	4,37	0,1	29,00	0,05	0,0
2	47,63	4,5	14,03	1,95	4,8
3	8,92	0,4	9,49	0,98	1,1
4	82,86	16,8	15,46	3,77	19,7
5	168,18	28,5	20,06	6,35	27,7
6	148,95	24,8	21,50	5,10	21,8
7	84,18	3,9	24,42	2,61	3,1
8	74,70	20,6	18,57	3,03	21,5
Total *Yhteensä*	96,32	100,0	19,20	3,75	100,0

Appendix 2 a. Area percentages of land-use classes and land classes, and their variances

Liite 2 a. Maaluokkien ja alaluokkien pinta-alaprosentit ja niiden varianssit

Material *Aineisto*		Method *Menetelmä*	Land-use class — *Maaluokka*																Land class — *Alaluokka*							
			1	2	3	4	5	6	7	1—7	1	2	3	4	5	6	7	mean[1] *kesk.*[1]	1	2	3	1—3	1	2	3	mean[1] *kesk.*[1]
			prop. % — *Osuus %*								Var. of prop. % — *Osuuden var. %*								Prop. % — *Osuus %*				Var. % — *Var. %*			
The 1967 material *Aineisto 1967*	1	Field, tot. invent. *Maasto, täysinv.*	71	3	1	7	0	2	16	100	—	—	—	—	—	—	—	—	51	8	17	75	—	—	—	—
	2	Grouping method *Ryhm. men.*	72	3	1	7	0	2	16	100	1,77	2,96	0,64	1,94	0,05	1,63	0,23	1,55	51	8	17	76	6,74	8,52	7,27	7,04
	3	Grouping method *Ryhm. men.*	71	3	1	7	0	2	16	100	4,14	3,63	1,59	1,25	0,27	1,84	0,29	3,22	50	8	16	75	7,02	8,37	7,12	7,19
	4	Random sampl. *Sat. otanta*	71	2	1	7	0	2	16	100	19,69	2,24	1,51	10,87	0,07	1,53	9,34	16,41	51	8	16	75	43,35	7,64	17,69	34,25
	13	Grouping method *Ryhm. men.*	71	3	1	7	0	2	16	100	1,82	1,21	0,23	0,86	0,05	0,32	0,85	1,53	51	7	18	75	2,25	2,52	1,54	2,11
	14	Grouping method *Ryhm. men.*	71	3	1	8	0	2	16	100	2,79	0,71	0,41	1,14	0,19	0,38	0,14	2,12	49	9	17	75	6,11	2,56	3,65	5,12
	15	Random sampl. *Sat. otanta*	70	3	1	7	0	2	16	100	7,25	1,31	0,63	4,95	0,03	0,79	5,43	6,43	51	8	15	74	19,40	4,52	8,20	15,50
The 1968 material *Aineisto 1968*	16	Field, tot. invent. *Maasto, täysinv.*	79	2	1	7	0	0	10	100	—	—	—	—	—	—	—	—	58	10	14	82	—	—	—	—
	17	Grouping method *Ryhm. men.*	79	2	2	8	0	0	10	100	3,97	1,90	1,40	0,92	0,10	0,15	0,30	3,28	57	10	14	81	9,58	7,90	4,64	8,51
	18	Random sampl. *Sat. otanta*	80	2	1	7	0	0	10	100	17,53	2,44	0,87	9,42	—	0,33	9,33	15,62	58	10	14	82	17,03	5,17	13,26	14,92
	19	Grouping method *Ryhm. men.*	79	2	1	7	0	0	10	100	1,55	0,81	0,43	0,35	0,02	0,08	0,17	1,29	58	10	14	82	4,01	5,16	2,12	3,82
	20	Strat. a *Strat. a*	79	2	1	8	0	0	10	100	1,11	0,60	0,34	0,48	0,03	0,10	0,19	0,95	58	9	15	82	5,34	4,95	4,19	5,09
	21	Strat. b *Strat. b*	79	2	2	8	0	0	10	100	1,82	0,84	0,87	0,42	0,04	0,07	0,13	1,51	..	..	..	..	..	..	..	..

[1]) For means of variances, weights corresponding to proportions of the classes have been used

[1]) *Keskimääräisten varianssien laskennassa on käytetty painoina luokkien osuuksia*

Appendix 2 b. Mean volumes on normal and poorly productive forest land, and their variances by tree species
Liite 2 b. Metsä- ja kitumaan keskikuutiot ja niiden varianssit puulajeittain

Material *Aineisto*		Method *Menetelmä*	Forest land — *Metsämaa*								Poorly prod. for. land — *Kitumaa*								Total area *Koko alue*	
			Mean vol. m³/ha *keskik. m³/ha*				Var. m³/ha *Var. m³/ha*				Mean vol. m³/ha *Keskik. m³/ha*				Var. m³/ha *Var. m³/ha*				Mean m³/ha *Keskik. m³/ha*	Var. m³/ha *Var. m³/ha*
			Pi *Mä*	Sp *Ku*	B-L *Lp*	Total *Yht.*	Pi *Mä*	Sp *Ku*	B-L *Lp*	Total *Yht.*	Pi *Mä*	Sp *Ku*	B-L *Lp*	Total *Yht.*	Pi *Mä*	Sp *Ku*	B-L *Lp*	Total *Yht.*		
The 1967 material *Aineisto 1967*	1	Field, tot. invent. *Maasto, täysinv.*	28	48	18	93	—	—	—	—	6	—	0	6	—	—	—	—	67	—
	2	Grouping method *Ryhm.men.*	27	46	19	93	15,7	21,8	5,4	20,4	9	—	0	10	157,0	—	0,5	53,7	67	7,9
	3	Grouping method *Ryhm.men.*	28	48	18	94	33.0	28,5	4,8	48,9	5	—	0	6	523,3	—	0,8	21,6	67	14,0
	4	Random sampl. *Sat.otanta*	28	48	18	94	18,6	26,4	11,7	48,4	6	—	0	6	14,8	—	0,4	14,2	67	41,4
	13	Grouping method *Ryhm.men.*	27	48	18	94	10,2	11,0	5,2	24,4	6	—	0	7	10,0	—	0,3	8,9	66	7,4
	14	Grouping method *Ryhm.men.*	27	48	18	93	7,0	5,9	3,4	10,3	6	—	0	6	9,0	—	0,0	9,0	66	5,3
	15	Random sampl. *Sat.otanta*	28	48	18	94	3,3	14,1	5,1	28,2	6	—	1	6	9,3	—	0,9	8,9	66	20,3
The 1968 material *Aineisto 1968*	16	Field, tot. invent. *Maasto, täysinv.*	26	53	21	99	—	—	—	—	8	1	3	12	—	—	—	—	79	—
	17	Grouping method *Ryhm.men.*	25	53	20	98	15,4	17,4	10,3	20,0	9	1	6	15	1120,6	2,9	155,1	451,5	78	7,0
	18	Random sampl. *Sat.otanta*	26	53	20	99	16,7	37,1	7,8	73,2	6	1	3	9	60,9	2,5	51,4	129,1	79	71,3
	19	Grouping method *Ryhm.men.*	25	53	20	99	8,5	10,3	3,5	11,4	8	1	3	13	29,2	1,9	20,0	78,5	78	5,2
	20	Strat.a *Strat.a*	26	53	20	100	11,2	10,8	3,8	12,2	7	1	3	11	26,1	0,8	14,2	51,1	79	6,1
	21	Strat.b *Strat.b*	25	53	20	98	9,8	9,1	4,5	9,7	..	..	..	..	..	..	..	..	78	4,2

Appendix 3
Liite 3
Inventory situation a11
Inventointitilanne a11
Assumptions:
Olettamukset:

— aerial photo 1:22 000
ilmakuva 1:22 000
— one photo plot represents 20 ha
yksi ilmakuvakoeala edustaa 20 ha
— one field plot represents 400 ha
yksi maastokoeala edustaa 400 ha
— 100 photo plots (= 2 000 ha) are interpreted per day
päivässä tulkitaan 100 ilmakuvakoealaa (= 2 000 ha)
— 2 000/400 = 5 field plots are measured on the area interpreted per day
päivän tulkinta-alueelle mitataan 2 000/400 = 5 maastokoealaa
— 8 field plots are measured per day
päivässä mitataan 8 maastokoealaa
— cost/2 000 ha:
kustannukset/2 000 ha:

aerial photos (2 000/439) 12 *ilmakuvat (2 000/439) 12*	=	55 mk	= 20.8 %
interpretation *tulkinta*	=	60 mk	= 22.6 %
field plots (5/8) 240 *maastokoealat (5/8) 240*	=	150 mk	= 56.6 %
Total *Yhteensä*	=	265 mk	= 100.00 %

Efficiencies:
Tehokkuudet:

Characteristic surveyed *Inv. tunnus*		Group./Random *Ryhm.men./Sat.ot.*	System./Random *System./Sat.ot.*	Group./System. *Ryhm./System.*
Forest land prop. *Metsämaan osuus*		1.988	1.198	1.66
Mean vol. on *Keskikuutio*	whole area *koko alueella*	1.959	1.299	1.51
	forest land *metsämaalla*	0.917	1.193	0.77
	site-fert.class *kasvup. luokka*	0.562	1.193	0.47
	treatment class *kehitysluokka*	0.553	1.193	0.46
	tree species *puulajeilla*	0.507	1.193	0.42

Coefficients used:
Käytetyt kertoimet:

Characteristic *Tunnus*	k_1	k_2	k_3	$400/k_3$ 1)
Forest land prop. *Metsämaan osuus*	1.0949	1.9343	2.3386	171
Mean volume, whole area *Keskik., koko alue*	1.1231	1.9841	2.4143	166
Mean volume, forest land *Keskik., metsäm.*	1.0312	1.8218	2.1706	184
Others *Muut*	1.0312	1.8218	2.1706	184

1) Area represented by field plot in systematic sampling = $400/k_3$
1) *Maastokoealan edustama pinta-ala systemattisessa otannassa = $400/k_3$*

Appendix 3
Liite 3
Inventory situation a_{22}
Inventointitilanne a_{22}
Assumptions:
Olettamukset:
— aerial photo 1:22 000
ilmakuva 1:22 000
— one photo plot represents 9 ha
yksi ilmakuvakoeala edustaa 9 ha
— one field plot represents 120 ha
yksi maastokoeala edustaa 120 ha
— 100 plots = 900 ha are interpreted per day
päivässä tulkitaan 100 koealaa = 900 ha
— 900/120 = 7.5 field plots are measured on the area interpreted per day
päivän tulkinta-alueelle mitataan 900/120 = 7.5 maastokoealaa
— 10 field plots are measured per day
päivässä mitataan 10 maastokoealaa
— cost/900 ha:
kustannukset/900 ha:

aerial photos *ilmakuvat*	(900/439) 12	= 24.6 mk	= 9.3 %
interpretation *tulkinta*	.....	= 60.0 mk	= 22.7 %
field plots *maastokoealat*	(900/120)/10 · 240	= 180.0 mk	= 68.0 %
	Total *Yhteensä*	264.6 mk	= 100.0 %

Efficiencies:
Tehokkuudet:

Characteristic surveyed *Inv. tunnus*		Group./Random *Ryhm.men./Sat.ot.*	System./Random *System./Sat.ot.*	Group./System. *Group./System.*
Forest land prop. *Metsämaan osuus*		2.552	1.527	1.67
Mean vol. on *Keskikuutio*	whole area *koko alueella*	2.460	1.370	1.80
	forest land *metsämaalla*	1.194	1.326	0.90
	site-fert.class *kasvup. luokka*	0.732	1.326	0.55
	treatment class *kehitysluokka*	0.720	1.326	0.54
	tree species *puulajeilla*	0.660	1.326	0.50

Coefficients used:
Käytetyt kertoimet:

Characteristic *Tunnus*	k_1	k_2	k_3	$120/k_3$ 1)
Forest land prop. *Metsämaan osuus*	1.1259	1.6551	1.8222	66
Mean volume, whole area *Keskik., koko alue*	1.1790	1.7332	1.9231	62
Mean volume, forest land *Keskik., metsäm.*	1.0446	1.5355	1.6667	72
Others *Muut*	1.0446	1.5355	1.6667	72

1) Area represented by field plot in systematic sampling = $120/k_3$
1) *Maastokoealan edustama pinta-ala systemaattisessa otannassa* = $120/k_3$

Appendix 3
Liite 3
Inventory situation ass
Inventointitilanne ass
Assumptions.
Olettamukset:
— aerial photo 1:22 000
ilmakuva 1:22 000
— one photo plot represents 1.25 ha
yksi ilmakuvakoeala edustaa 1,25 ha
— one field plot represents 10 ha
yksi maastokoeala edustaa 10 ha
— 100 plots = 125 ha are interpreted per day
päivässä tulkitaan 100 koealaa = 125 ha
— 125/10 = 12.5 field plots are measured on the area interpreted per day
päivän tulkinta-alueelle mitataan 125/10 = 12.5 maastokoealaa
— 14 field plots are measured per day
päivässä mitataan 14 maastokoealaa
— cost/125 ha:
kustannukset/125 ha:

aerial photos *ilmakuvat*	(125/439) 12	=	3.4 mk =	1.2 %
interpretation *tulkinta*	.....	=	60.0 mk =	21.6 %
field plots *maastokoealat*	(125/10)/14 · 240	=	214.2 mk =	77.2 %
	Total *Yhteensä*		277.6 mk =	100.0 %

Efficiencies:
Tehokkuudet:

Characteristic surveyed *Inv. tunnus*		Group./Random *Ryhm.men./Sat.ot.*	System./Random *System./Sat.ot.*	Group./System *Ryhm./System.*
Forest land prop. *Metsämaan osuus*		3.061	2.299	1.33
Mean vol. on *Keskikuutio*	whole area *koko alueella*	2.927	1.608	1.82
	forest land *metsämaalla*	1.446	1.718	0.84
	site-fert.class *kasvup. luokka*	0.886	1.718	0.52
	treatment class *kehitysluokka*	0.872	1.718	0.51
	tree species *puulajeilla*	0.799	1.718	0.47

Coefficients used:
Käytetyt kertoimet:

Characteristic *Tunnus*	k_1	k_2	k_3	$10/k_3$ 1)
Forest land prop. *Metsämaan osuus*	1.1688	1.5147	1.5191	6.5
Mean volume, whole area *Keskik., koko alue*	1.2424	1.6102	1.6158	6.2
Mean volume, forest land *Keskik., metsäm.*	1.0594	1.3730	1.3763	7.3
Others *Muut*	1.0594	1.3730	1.3763	7.3

1) Area represented by field plot in systematic sampling = $10/k_3$
1) *Maastokoealan edustama pinta-ala systemaattisessa otannassa = $10/k_3$*

Appendix 3
Liite 3
Inventory situation b_{11}
Inventointitilanne b_{11}
Assumptions:
Olettamukset:
— aerial photo 1:30 000
ilmakuva
— one photo plot represents 20 ha
yksi ilmakuvakoeala edustaa 20 ha
— one field plot represents 400 ha
yksi maastokoeala edustaa 400 ha
— 100 plots (=2000 ha) are interpreted per day
päivässä tulkitaan 100 koealaa (= 2 000 ha)
— 200/400 = 5 field plots are measured on the area interpreted per day
päivän tulkinta-alueelle mitataan 2000/400 = 5 maastokoealaa
— 8 field plots are measured per day
päivässä mitataan 8 maastokoealaa
— cost/2000 ha:
kustannukset/2000 ha:

aerial photos *ilmakuvat*	(2000/1333) 12	=	18 mk	= 7.9 %
interpretation *tulkinta*	.....	=	60 mk	= 26.3 %
field plots *maastokoealat*	.....	=	150 mk	= 65.8 %
	Total *Yhteensä*		228 mk	= 100.0 %

Efficiencies:
Tehokkuudet:

Characteristic surveyed *Inv. tunnus*		Group./Random *Ryhm.men./Sat.ot.*	System./Random *System./Sat.ot.*	Group./System *Ryhm./System.*
Forest land prop. *Metsämaan osuus*		2.401	1.144	2.10
Mean vol. on *Keskikuutio*	whole area *koko alueella*	2.365	1.277	1.85
	forest land *metsämaalla*	1.109	1.172	0.94
	site-fert.class *kasvup. luokka*	0.680	1.172	0.58
	treatment class *kehitysluokka*	0.669	1.172	0.57
	tree species *puulajeilla*	0.613	1.172	0.52

Coefficients used:
Käytetyt kertoimet:

Characteristic *Tunnus*	k_1	k_2	k_3	$400/k_3$ 1)
Forest land prop. *Metsämaan osuus*	1.0949	1.6642	1.9365	207
Mean volume, whole area *Keskik., koko alue*	1.1231	1.7071	2.0000	200
Mean volume, forest land *Keskik., metsäm.*	1.0312	1.5674	1.7950	223
Others *Muut*	1.0312	1.5674	1.7950	223

1) Area represented by field plot in systematic sampling = $400/k_3$
1) *Maastokoealan edustama pinta-ala systemaattisessa otannassa* = $400/k_3$

Appendix 3
Liite 3
Inventory situation b_{22}
Inventointitilanne b_{22}
Assumptions.
Olettamukset:
— aerial photo 1:30 000
ilmakuva 1:30 000
— one photo plot represents 9 ha
yksi ilmakuvakoeala edustaa 9 ha
— one field plot represents 120 ha
yksi maastokoeala edustaa 120 ha
— 100 photo plots (=900 ha) are interpreted per day
päivässä tulkitaan 100 koealaa (= 900 ha)
— 900/120=7.5 field plots are measured on the area interpreted per day
päivän tulkinta-alueelle mitataan 900/120=7.5 maastokoealaa
— 10 field plots are measured per day
päivässä mitataan 10 maastokoealaa
— cost/900 ha:
kustannukset/900 ha:

aerial photos *ilmakuvat*	(900/1333) 12	=	8.1 mk	= 3.3 %
interpretation *tulkinta*	900 ha	=	60.0 mk	= 24.2 %
field plots *maastokoealat*	(900/120)/10 · 240	=	180.0 mk	= 72.6 %
	Total *Yhteensä*	=	248.1 mk	= 100.0 %

Efficiencies:
Tehokkuudet:

Forest land prop. *Metsämaan osuus*		Group./Random *Ryhm.men./Sat.ot.*	System./Random *System./Sat.ot.*	Group./System *Ryhm./System.*
Characteristic surveyed *Inv. tunnus*		2.752	1.497	1.84
Mean vol. on *Keskikuutio*	whole area *koko alueella*	2.652	1.391	1.91
	forest land *metsämaalla*	1.286	1.305	0.99
	site-fert.class *kasvup. luokka*	0.789	1.305	0.60
	treatment class *kehitysluokka*	0.776	1.305	0.59
	tree species *puulajeilla*	0.711	1.305	0.54

Coefficients used:
Käytetyt kertoimet:

Characteristic *Tunnus*	k_1	k_2	k_3	$400/k_3$ 1)
Forest land prop. *Metsämaan osuus*	1.1259	1.5519	1.6898	71
Mean volume, whole area *Keskik., koko alue*	1.1790	1.6251	1.7838	67
Mean volume, forest land *Keskik., metsäm.*	1.0446	1.4397	1.5470	78
Others *Muut*	1.0446	1.4397	1.5470	78

1) Area represented by field plot in systematic sampling = $120/k_3$
1) *Maastokoealan edustama pinta-ala systemaattisessa otannassa* = $120/k_3$

Appendix 3
Liite 3
Inventory situation b_{33}
Inventointitilanne b_{33}
Assumptions:
Olettamukset:

— aerial photo 1:30 000, 23x23 cm = 4761 ha (stereop. ~ 1333 ha)
ilmakuva 1:30 000, 23x23 cm = 4761 ha (stereop. ~ 1333 ha)
— one photo plot represents 1.25 ha
yksi ilmakuvakoeala edustaa 1.25 ha
— one field plot represents 10 ha
yksi maastokoeala edustaa 10 ha
— 100 photo plots (= 125 ha) are interpreted per day
päivässä tulkitaan 100 koealaa (= 125 ha)
— 125/10 = 12.5 field plots are measured on the area interpreted per day
päivän tulkinta-alueelle mitataan 125/10 = 12.5 maastokoealaa
— 14 field plots are measured per day
päivässä mitataan 14 maastokoealaa
— cost/125 ha:
kustannukset/125 ha:

aerial photos *ilmakuvat*	(125/1333) 12	=	1.0 mk =	0.4 %
interpretation *tulkinta*	.....	=	60.0 mk =	21.8 %
field plots *maastokoealat*	(12.5/14) 240	=	214.3 mk =	77.8 %
	Total *Yhteensä*		275.3 mk =	100.0 %

Efficiencies:
Tehokkuudet:

Characteristic surveyed *Inv. tunnus*		Group./Random *Ryhm.men./Sat.ot.*	System./Random *System./Sat.ot.*	Group./System *Ryhm./System.*
Forest land prop. *Metsämaan osuus*		3.088	2.294	1.35
Mean vol. on *Keskikuutio*	whole area *koko alueella*	2.954	1.608	1.84
	forest land *metsämaalla*	1.459	1.718	0.84
	site-fert.class *kasvup. luokka*	0.895	1.718	0.52
	treatment class *kehitysluokka*	0.880	1.718	0.51
	tree species *puulajeilla*	0.807	1.718	0.47

Coefficients used:
Käytetyt kertoimet:

Characteristic *Tunnus*	k_1	k_2	k_3	$10/k_3$ 1)
Forest land prop. *Metsämaan osuus*	1.1688	1.5015	1.5058	6.6
Mean volume, whole area *Keskik., koko alue*	1.2424	1.5961	1.6013	6.2
Mean volume, forest land *Keskik., metsäm.*	1.0594	1.3610	1.3639	7.3
Others *Muut*	1.0594	1.3610	1.3639	7,3

1) Area represented by field plot in systematic sampling — $10/k_3$
1) *Maastokoealan edustama pinta-ala systemaattisessa otannassa* = $10/k_3$

WIND-INDUCED ROOT MOVEMENTS IN FOREST TREES

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Suomenkielinen selostus

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1. INTRODUCTION

One of the main functions of tree roots is to attach the stem firmly to the soil. However, relatively little attention has been paid to the question whether trees are really held steadily in the soil, or whether the stem, which may weigh several tons, causes movements or breakages in the roots, when bending under the action of wind or snow pressure.

The effects of air currents on forests have been the object of a great number of investigations and studies of the influence of wind on tree physiology are also numerous. As early a writer as R a m a n n (1911, p. 457) realized that the movements of tree roots in storms and strong winds may have a considerable influence on the soil structure, and he cites an anonymous observer, who reported that the roots in old spruce stands may rise as much as a foot when the stems are bent by the wind. R e u s s (1889) and N e g e r (1924) describe attempts to prevent the windthrow of spruce by weighing down the surface roots with stones. F r i t z s c h e (1933), and P r i e h ä u s s e r (1943) mention that before a spruce falls, the root plate (Wurzelteller) may rise as much as 10 cm, and that the sinker roots are the first to break. H ü t t e (1964, 1967, 1968) mentions that the movements of the root plate of spruce trees became smaller, when parts of the tree crowns were removed, and the process of uprooting by wind is very comprehensively described. According to M o o r e (1933), P e a c e (1962) and G r a s s o (1965), the root systems of young pines may become damaged when the wind causes them to rub against stones in the soil. S h a v n i n (1966) reports observations in the Central Urals of movements of pine roots within the soil during storms. K ö s t l e r, B r ü c k n e r and B i b e l r i e t h e r (1968, p. 64) relate that as a result of root movements during a serious storm in an old beech stand »wurde zwischen den Horizontalwurzeln bis 2 m vom Stamm breiartiges Bodenmaterial bis fusshoch emporgeworfen». H e r m a n n and P e t e r s e n (1969) suppose that the stunted ends of tree roots deep in the soil result from rubbing against stones in strong winds, and wind-induced movement has also been proposed as the reason for the formation of root grafts (F a b r i c i u s 1927, Y l i - V a k k u r i 1953). It is often suggested that storms and wind, as well as snow, cause root

injuries, especially in spruce (Borggreve 1873, Blomqvist 1883, Bargmann 1904, Matthes 1911, Heikinheimo 1920, Kokkonen 1923, Samuelsson 1925, Laitakari 1930, Kangas 1946, p. 187, Köstler 1962, Köstler, Brückner & Bibelriether 1968), although direct evidence seems to be largely lacking. E.g. Redmond (1954) was not able to detect root injuries after a hurricane in yellow birch in Nova Scotia in sandy loam soil.

These citations show that the phenomenon of root movements of forest trees in wind is quite well known. In addition, experienced forest workers know that in stormy weather the soil, especially in spruce stands, often rises and falls. Exact knowledge, however, is very scanty and the observations quoted above were mainly based on ocular estimation; practically no measurements relating to root movements have been published. The phenomenon may be supposed to be more pronounced in Nordic conditions, where the major part of the roots of trees, especially of spruce, are often situated in loose peat or raw humus, which are evidently much less firm attachment media than soils with profiles of the mull type. Questions which seem to have been more or less neglected are: how common the root movements are, in which conditions they occur, what the magnitude of the movements is, and how they effect the morphology of the root systems and also the humus layer.

This investigation was started in connection with studies on the infection biology of *Armillaria mellea*, which colonizes living trees through root wounds. During the work, it turned out that the problem of root movements in forest soils involves a large and many-sided complex of phenomena, which evidently needs a separate study. However, the main aim of the present investigation was to elucidate possible pathways of penetration of decay fungi into tree roots. It was limited mainly to Scotch pine (*Pinus silvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.), which are the important tree species in Finland.

2. OBSERVATIONS ON MOVEMENTS OF TREE ROOTS IN SOIL

21. Movements of roots in artificially inclined trees

As simultaneous measurements of sudden root movements caused by wind in different parts of the root system proved to be difficult to carry out, the investigation was started by inclining stems artificially, and by measuring the corresponding changes in root positions.

Method. A steel or nylon wire was fastened to the stem at a height of 4—8 m, and the stem was pulled with a mechanical winch from a distance

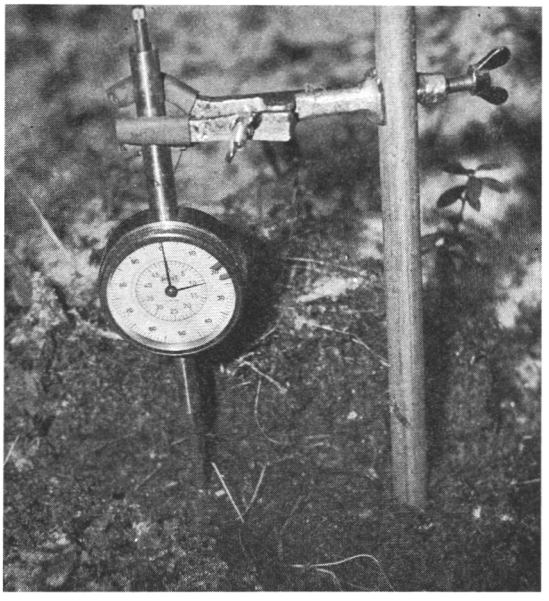

Fig. 1. Arrangement for measuring the vertical movement of a root. The sensing rod of the dial indicator rests on a spruce root, and the indicator is fixed immovably to the ground by means of an aluminium rod. 1 division on the outer scale of the dial corresponds to a movement of 0.01 mm.

Kuva 1. Juuren pystysuoran liikkeen mittaaminen mittakellolla, jonka uloimman asteikon mittavälit vastaavat 0.01 mm:n liikettä.

of ca. 10 m. The pulling was monitored with a dynamometer of 100 kg capacity and by measuring the inclination angle of the stem at breast height with a clinometer constructed from a commercial water level. The tree was selected so that a normal root lying parallel to the pull was found near the surface on each side of the stem. Humus and the rhizomes of dwarf shrubs were removed as well as a small amount of mineral soil, if necessary. Beside the root an aluminium rod was forced to a depth of ca. 50 cm, so that it penetrated the mineral soil. A dial indicator (Mauser 662 or 682) was fixed to the rod with a burette-holder (Fig. 1). The dial used was graduated to indicate movements of 0.01 mm and one rotation of the longer pointer corresponded to one millimetre. Horizontal movements were measured by placing the dial indicator in a horizontal position, with its sensing rod touching the vertical surface of a cut made in the root with a knife. Vertical movements were recorded by placing the indicator with its sensing rod touching the smoothened upper side of the root at different distances from the stem. Previous pulling experiments (e.g. Fraser 1962, Fraser & Gardiner 1967) have indicated that besides the tree species, the quality

of the soil plays a decisive role in the stability of a tree. For this reason pulling experiments were made with both pine and spruce and in sand, clay and peat soils. All the experiments were made at Ruotsinkylä Experimental Forest about 25 km north of Helsinki. Recorded movements are presented in Table 1 and shown graphically in Figs. 2 and 3. Altogether 13 pines and 11 spruces were pulled.

Eight pines were pulled on sandy soil; their height was 12.5—19.0 m and their d.b.h. 16—21 cm. Both vertical and horizontal movements of the main lateral roots were readily demonstrable, but the movements were small compared with those of the trees in the other soil types. This is evidently due to the fact that in the sandy soil the main bending took place in the stem, while in other soil types it occurred in the root systems. The relation of the vertical and horizontal movements varied considerably, and in some trees only horizontal movements were found on the opposite side to the pull. This seems to depend on the diameter of the roots measured. The thicker the roots were, the greater was the vertical movement. On the side of the pull the roots sank slightly less than they rose on the opposite side, and moved slightly in the direction of the pull. In the thinner roots in the peripheral parts (1—1.5 m from the stem) of the root system definite horizontal (longitudinal) movements were recorded.

The movements of the tap root estimated by forcing a solid aluminium rod (diameter 8 mm) through humus and sand, so that it penetrated the tap root at an angle of approximately 70° to its long axis, at a depth of 25—30 cm from the surface of the humus. The rod was fixed so firmly that it moved in both directions with the movements of the tap root despite of sand friction. In all cases a definite movement was found in the tap root even at inclinations of 1°, and it was clearly away from the pull, i.e. the stem and the tap root bent in opposite directions. It seems that the main surface roots attach the stem so rigidly that the thick tap root must move in the opposite direction. At an inclination of 3° the average tap root movement was 0.5 mm, the maximum being 1.40 mm, at a depth of 25—30 cm.

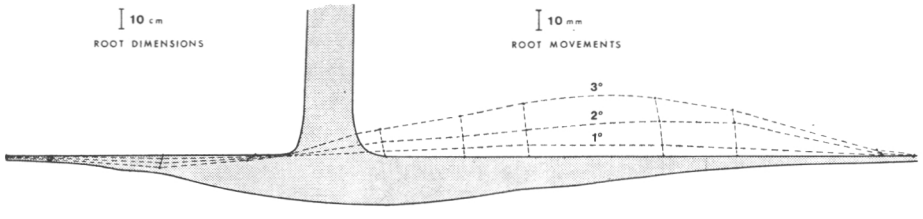

Fig. 2. Movements of roots of a spruce (d.b.h. 22 cm) growing on clay soil, when artificially inclined to the left 1, 2, and 3 degrees.

Kuva 2. Savimaalla kasvavan kuusen (läpimitta 22 cm) juuriston liikkeet, kun runkoa kallistettiin 1, 2 ja 3 astetta.

The pines on clay soils behaved similarly, although the movements were considerably greater, and the vertical movement exceeded the horizontal movement. The tap root moved in the same way. Fig. 2 depicts fairly typical movements.

According to Kokkonen (1923) and Heikurainen (1955) pines on peaty soil do not develop tap roots, and in this study such pines were moved much more easily than those on mineral soil. The movement was approximately eight times as great as that on sandy soil (Table 1).

The spruces investigated had no tap roots. On sandy soil the movements were slightly greater than in pines. Especially the vertical movement was more pronounced.

In clay soils the spruces had developed a typical root plate, which in some cases scarcely seemed to be attached to the underlying mineral soil, judging by the small power needed to pull the tree. The maximum rise took place at a distance of 60—120 cm, beyond which the roots become so thin that they bend. Consequently, the Fig. 3 indicates that the greatest bending takes place in the peripheral parts of the surface roots, and not at the base of the stem, as it seems to do in pine, at least in some cases. Root movements of this type have also been indicated by the way in which the snow cover is disturbed (see p. 41 and Fig. 33).

Table 1. Upward movement (mm) of main lateral roots at a distance of 40—50 cm from the stem, on the opposite side to the pull, when the stem was inclined with a winch.
Taulukko 1. Pinnansuuntaisen juuren nousu millimetreissä 40—50 cm:n etäisyydellä rungosta vedosta poispäin olevalla puolella puuta, kun runkoa kallistettiin 1—3 astetta

Species *Puulaji*	Soil *Maalaji*	Number of trees *Puiden lukumäärä*	Average rise (mm) at inclinations of *Keskimääräinen nousu (mm)* 1°	2°	3°
Pine — *Mänty*	Sand — *Hiekka*	8	0.46	1.09	2.09
	Clay — *Savi*	2	0.95	2.80	4.95
	Peat — *Turve*	3	3.63	8.90	16.30
Spruce — *Kuusi*	Sand — *Hiekka*	6	1.43	3.22	5.77
	Clay — *Savi*	5	3.12	7.40	13.62

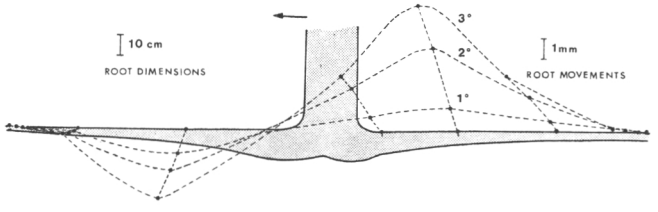

Fig. 3. Root movements of a pine tree (d.b.h. 24 cm) when the stem is inclined artificially 1, 2, and 3 degrees.
Kuva 3. Männyn (d 1.3 24 cm) juuriston liikkeet, kun runkoa kallistettiin 1, 2 ja 3 astetta.

Measurements of the bending of tree stems in wind were carried out in corresponding way in order to ascertain whether the inclinations used in winching do occur in nature.

In pines the largest inclination found was 2 ¼° in a 9 B storm in trees with d.b.h. 21—34 cm growing on till soil. In 3—5 B wind the bending was not so great, only 10′—30′, in smaller trees somewhat more. In an equal wind in spruces inclinations up to 50′ were recorded, and in 6 B wind 2° 30′. From Fig. 9 it is seen that in the tree individual in question, inclinations of the base of over 2° occurred about 20 times in 80 days and inclinations over one degree were abundant. Consequently inclinations of 1° must in most cases be regarded as occurring in nature.

The pulling experiments show that the roots definitely move when the stem is inclined 1°. The magnitude of the movement depends greatly on the tree species, development of the root system, root diameter, size of the tree, and the soil material. In general, however, the movements seem to be fairly regular.

When the pull was released. the root system in most cases did not settle back into its original position, but remained slightly inclined, approximately ½ degree if the tree had been inclined up to 3 degrees. In certain cases, where root breakages had evidently occurred (cracking sounds and sudden movements observed when pulling), the tree remained even more inclined.

In connection with the pulling experiments some preliminary observations were made on the energy needed to incline a tree, by calculating the perpendicular power, and from this the turning force at the base. Very definite differences were found between trees of approximately the same size but of different species. On clay soils, the pulling power needed for an inclination of one degree, was 124, 214, 211, and 232 kpm for spruces, and 583 and 587 kpm for pines of approximately same size. In sandy soil, about twice as much power was required to incline spruce, and in peat soils pines were inclined with about half the power required in clay soil. Although the material is small, evidently there are great differences in the strength of attachment of different trees.

The reliability of the method used greatly depends on whether the aluminium rods are fixed deep enough in the soil to prevent their moving with the roots. This is relatively easy to arrange in clay and peat soils, but in sandy soils, where pines develop a long tap root, movements of the rods may considerably affect the results. An attempt was made to investigate the movements of the surface sand by the following method: a plank was suspended at a small distance from the ground, being fastened to two aluminium rods placed on either side of the tree at a distance of 2 m from its base, and to it dial indicators were fixed the sensing rods of which rested on wooden blocks lying on the ground. Fig. 4 shows an average case of

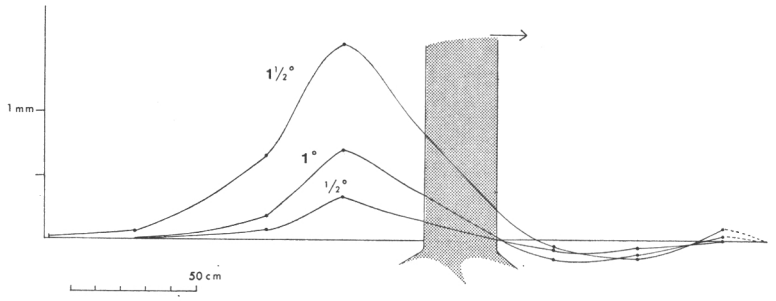

Fig. 4. Soil movements when a 28-cm-thick pine is inclined ½, 1, and 1 ½ degrees.
Kuva 4. Pintamaan liikkeet, kun 28 cm:n läpimittaista mäntyä kallistettiin 1/2, 1 ja 1 1/2 astetta.

movements of the surface soil: on the pulling side the soil at first sinks, but later rises, probably due to the twisting of the roots. On the opposite side a rise in the ground may be noted up to about 150 cm from the stem, the maximum occurring about 50 cm from the stem. On some occasions the ground appeared to sink at about 150 cm. The movements of the deeper layers of the sand were investigated by pushing aluminium rods deep into the soil, wire being wound around their lower ends to fasten them to the soil. It was found that the sand moved down to a depth of approximately 50 cm. These observations indicate, that when the stem is bent in strong winds, the sand may move with the tree roots to a considerable depth. This is also shown by windthrown pines, which generally have large amounts of sand (sometimes up to 1 m^3) attached to their root systems. Smaller movements must also occur before the actual blow-down, and this fact should be taken into account as a possible source of error, when measurements are made on roots in sand soil.

22. Movements of tree roots in wind

After preliminary information on root movements had been obtained by inclining trees artificially, observations were made on root movements during strong winds and storms. The aim was to get information on how common and large these movements are and at which wind speeds movement is initiated.

221. Methods

Three methods were used to estimate the root movements:

Method 1. This was similar in principle to that used in the experiments

described above (p. 7). Dial indicators attached to aluminium rods, were used to record horizontal and vertical movements. However, usually only one indicator was used per tree in order to get information on a larger number of trees. As a standard method for the vertical movements the sensing rod of the dial indicator was placed on the smoothened upper side of a main lateral surface root at a distance of ½ m from the centre of the stem on the windward side of the tree.

The indicators used were fairly sensitive and often registered movements due to other factors than the wind, e.g. the movements of the observer. However, one soon learns to distinguish movement induced by gusts of wind from that due to other causes. In the cases described below, it took at least 2—3 min. to record the results. As the wind blows in gusts, the values obtained from different trees are thus not strictly comparable, not having been read simultaneously, but the general magnitude of the movement is apparent.

Wind measurements were obtained from the Meteorological Office of Helsinki Airport, which is situated approximately 2—5 km from the main area of investigation in Ruotsinkylä Experimental Forest, Tuusula parish. A portable Wallac thermoanemometer was also used, the wind being measured at 2 m height on lake shores, hill slopes or clear-cut areas before and after the root movement measurements. These measurements of wind speed in other locations must be regarded as approximate.

Method 2. A linear motion potentiometer, »Linipot», model 141, made by Bourns Inc., Riverside, California, which records movements with an accuracy of 0.01 mm, was attached to a tree root, and connected to recorder. An ordinary potentiometer was used to adjust the current for the recorder. The method is simple and reliable, but owing to the high cost of the potentiometer, its susceptibility to damage by movements exceeding the scale and its dependence on electricity, methods 1 and 3 were used as standard methods.

Method 3. The most suitable way of recording root movements proved to be a constructed root movement recorder, which simply with the aid of a lever magnifies the root movement 5—20 times and which marks the movements with a pen on a clock work-driven thermograph drum (Fig. 5).

222. Observations of root movements at different wind speeds and in different soils

During the summer and autumn of 1970 the following observations on root movements were made by method 1:

20. 5. 1970. Tuusula, Katila. Wind 4 Beaufort. Two spruces on clay soil. In one tree the continuous movement was 0.4—0.5 mm, the maximum

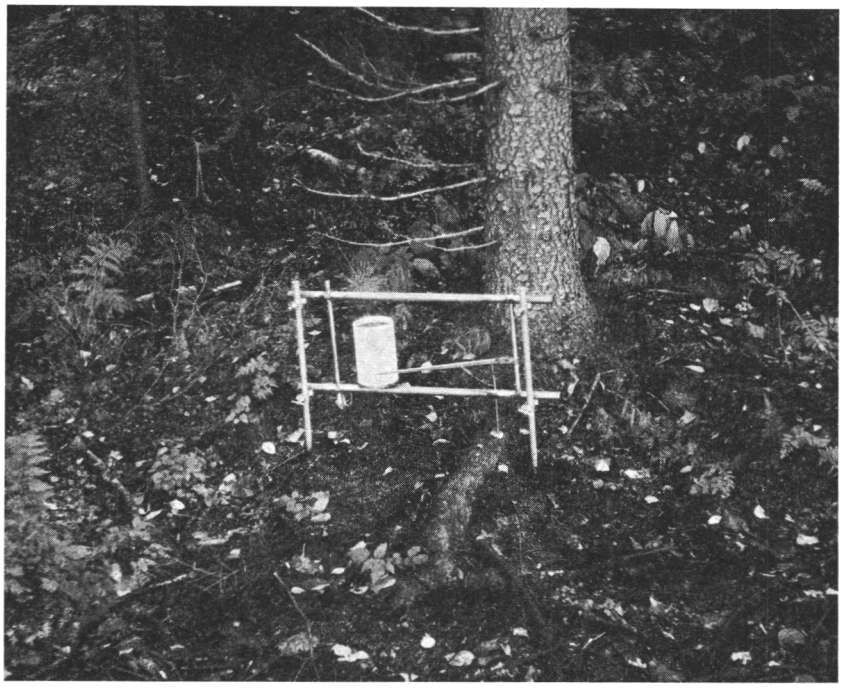

Fig. 5. Root movement recorder and the experimental arrangement, with which Fig. 9 was obtained. Metal rod attached to the root with plastic cement transmits the vertical movements of the root to the lever, which enlarges the movements 11 times to the thermograph drum. The recorder was covered with a rain shield of aluminium plate.
Kuva 5. Juuriliikepiirturi, jonka avulla saatiin kuvan 9 diagrammi. Juureen plastic paddingilla kiinnitetty metallisauva välittää liikkeet vipuun, joka suurentaa liikkeet 11-kertaisena termografin rummulle. Piirturi peitettiin aluminipeltisellä sadesuojuksella.

movement observed 3.5 mm; in the other the corresponding values were 1—2 mm and 5 mm.

13. 6. 1970. Tuusula, Ruotsinkylä. Wind 5—6 B. Closed spruce stand on drained peat soil. Seven spruces with a diameter over 30 cm had the following maximum movements: 4.2, 4.0, 3.4, 2.0, 1.2, 0.3 and 0.2 mm.

21. 6. 1970. Ruotsinpyhtää, Kampuslandet. Wind 5—7 B. Seven exposed spruce trees with d.b.h. over 17 cm on shallow peat or stony till soil. In three trees the movement was 0.05—0.1 mm, in one 0.7 mm, in two 3 mm, and in one 5.5 mm.

21. 6. 1970. Ruotsinpyhtää, Länsholmen. Wind 5—7 B. Exposed spruce stand on stony till soil. Thirty-eight trees were investigated, the d.b.h. of which were 10—25 cm, and all of which had a detectable movement, the average being less than 0.5 mm, and the largest one over 1 cm (Fig. 6, A).

27. 6. 1970. Ruotsinpyhtää, Gäddbergsö, exposed shore stand of spruce. Wind 4—5 B. Of nine spruces, with d.b.h. over 20 cm, one had a continuous movement of 5.3 mm, three 0.3—0.4 mm, three 0.1—0.2 mm, and in two no detectable movements were observed.

5. 7. 1970. Tuusula, Ruotsinkylä, Mätäkivi. Wind 5 B. In three exposed pines, with d.b.h. 20—25 cm, the horizontal movements of the surface roots were 0.05—0.08 mm, the vertical less than 0.02 mm. In all trees the horizontal movement was definitely larger than the vertical one. Six spruces with d.b.h. over 20 cm were investigated on peaty soil, and the vertical movement in one was 1 mm, and in the rest 0.2—0.5 mm. Five spruces of equal size and similar exposition were investigated on till soil, but no movement was observed.

13. 10. 1970. Lapinjärvi, Sammalberget. Wind 5—7 B. Exposed hill, mostly with rocky till soil. The movement of the tap root was investigated by forcing an aluminium rod into it so that the rod followed the movements of the root. Twelve pines, with d.b.h. over 20 cm, were examined; in five no movements were detectable, in five there was movement of 0.02—0.5 mm against the wind, i.e. in the opposite direction to the bending of the stem, and in two there was movement in the same direction as that of the stem. Five pines with d.b.h. over 30 cm on clay soil in the exposed border of a field had vertical root movements of 0.05—0.4 mm, which were readily detectable in all cases. Movement of surface sand similar to that shown in Fig. 4 was also observed. During gusts of wind, the surface gravel of a rapakivi heap, on which a pine tree with d.b.h. 16 cm was growing, rose in gusts about 0.2 mm at a distance of 27 cm from the stem, and 0.02—0.05 mm at a distance of 55 cm.

14. 10. 1970. Padasjoki, Vesijako, Sammallahdensuo. Wind 4—5 B. Closed spruce stand on peat soil (depth over 1 m). Fig. 6, B—C presents the movements of exposed trees, for which the average value was 0.52 mm, as well as those of trees ca. 100 m from the edge of the stand, which had an average of 0.08 mm.

20. 10. 1970. Tuusula, Ruotsinkylä, the hill Mätäkivenmäki. Wind gusts up to 9 B. Exposed pine trees with d.b.h. 21—34 cm had horizontal root movements of 0.18—0.26 mm, and vertical ones of 0.26—0.85 mm. The movement of the tap root was determined for 8 trees, and in five it was in the opposite direction to the bending of the stem. It measured about 0.05—0.3 mm, and occasionally the dial indicators registered movements of 1 mm, probably owing to interference from the movements of the soil.

9. 11. 1970. Tuusula, Korso. Wind 3 B. The vertical movement in 22 spruces on till soil and in 23 growing in a spruce swamp was determined.

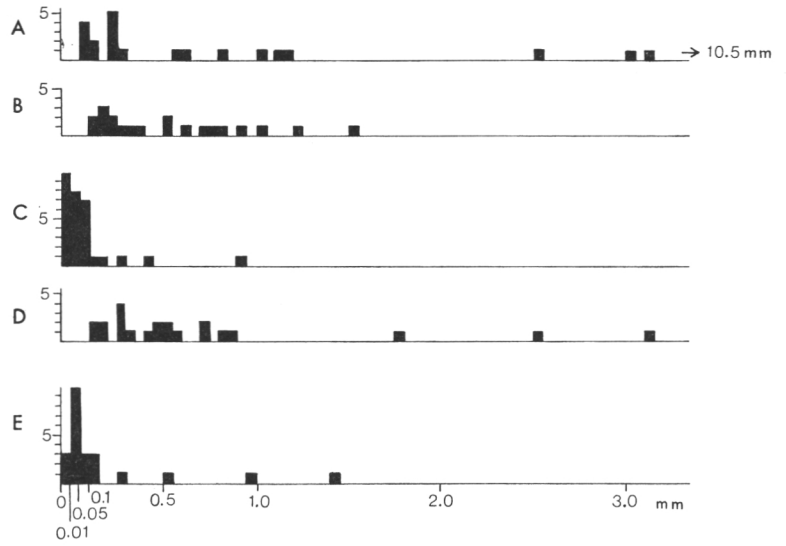

Fig. 6. Magnitude of vertical movement of surface roots of spruce (horizontal axis) at a distance of 50 cm from the stem on windward side in different trees and expositions. Vertical axis: number of trees. A: Ruotsinpyhtää, Länsholmen, exposed spruce stand on till soil, wind 5—7 B. B: Vesijako, Sammallahdensuo, exposed spruce stand on peat soil, wind 4—5 B. C: as in B, but in less exposed site in stand about 100 m from the margin. D: Tuusula, Ruotsinkylä, spruce swamp on shallow peat soil, not exposed, and E: exposed spruce stand on till soil, wind 3 B. Interval of about 30 min. between determinations of B and C, and also between D and E.

Kuva 6. Kuusen pintajuurten pystysuora liike 50 cm:n päässä rungosta tuulen puolella eri puuyksilöillä ja maalajeilla sekä eri tavoin tuulelle alttiilla paikoilla. Pystysuora akseli: tutkittujen puiden lukumäärä. A: Ruotsinpyhtää, Länsholmen, avoin rantametsä moreenimaalla, tuuli 5—7 B. B: Vesijako, Sammallahdensuo, aukea kuusimetsän reuna turvemaalla, tuuli 4—5 B. C: kuten B, mutta tutkitut puut sijaitsivat noin 100 m metsikön sisällä. D: Tuusula, Ruotsinkylä, ohutturpeisessa korvessa metsikön sisällä kasvavia puita. E: kuten D, mutta tuulelle altis metsänreuna moreenialustalla. Tuuli 3 B. — Määritysten B ja C sekä D ja E välinen aika noin puoli tuntia.

D.b.h. of all trees was over 20 cm. The mineral soil site was slightly more exposed to wind than the swamp. Fig. 6, D and E indicate that the movements in peat soil were definitely greater than those in mineral soil, where in some trees no movements were detected, while, remarkably, in others they were readily visible (up to 1.4 mm), evidently owing to defective root system.

Observations made with a linear motion potentiometer are illustrated in Figs. 7 and 8.

Fig. 7 shows movements of a large spruce, d.b.h. 42 cm, at different wind speeds, measured on a side root 75 cm from the stem base. The same measuring point was used in all cases. The soil was till, and the orientation of the roots was mostly downwards. Vertical motion began in 4—5 B wind, at first being registered only in stronger gusts. In 6—8 B wind the motion became continuous and its amplitude wider.

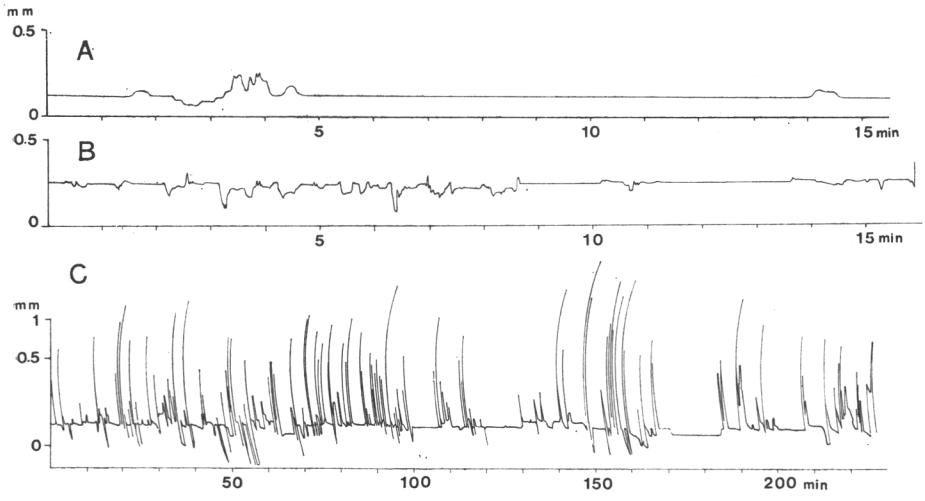

Fig. 7. Measurements of movements of a root of spruce (d.b.h. 42 cm) on till soil at A: 4 B, B: 5—6 B and C about 7 B wind. Measurements 70 cm from the stem base.

Kuva 7. Moreenialustalla kasvavan kuusen (d 1.3 42 cm) juuriston liikkeet A: 4 boforin, B: 5—6 ja C noin 7 boforin tuulessa. Mittaus noin 70 cm rungosta.

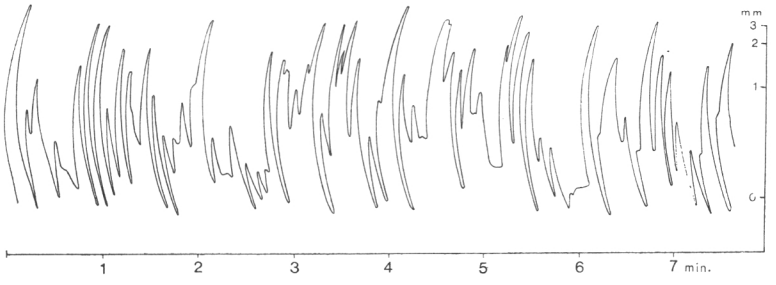

Fig. 8. Vertical movements of a root at a distance of 50 cm from the stem of a 20-m-high spruce on shallow peat soil, as measured with a linear motion potentiometer. Wind about 5 Beaufort. Tuusula, Ruotsinkylä.

Kuva 8. N. 20 m korkean turvealustalla kasvavan juuren liike 50 cm rungosta potentiometrivastuksella mitattuna. Tuuli noin 5 boforia. Tuusula, Ruotsinkylä.

Fig. 8 shows movements of a spruce root in a drained spruce swamp near Ruotsinkylä Experimental Station. The root attachment in this case was much looser and the range of movements wider. It is remarkable that movements of 1—3 mm occurred up to four times a minute.

In summer 1971 the vertical movements of a spruce root system were followed with aid of a root movement recorder in Ruotsinkylä Experimental

forest. The tree investigated was growing 1.7 km north of the Meteorological Observatory of Helsinki Airport, in a drained spruce swamp, the depth of the peat layer being 60—70 cm. The tree was situated ca. 20 m east from the border of an extensive clear-cut area (prolongation of airport runway), a few trees of equal size growing between. In north to south-east sides of the tree spruce forest of equal or higher size was growing and in addition in north and in east there was rocky elevations of 10—20 m height. Thus the tree was exposed to winds from south to north-west, and especially from south-west due to the topography.

The height of the tree was 17.5 m, d.b.h. 22 cm, weight of parts above soil was 282.7 kg, of which 69.7 kg foliage and branches, and weight above 5 m 164.7 kg. The sensing rod of the root movement recorder was placed on a root running SW from the stem at a distance of 45 cm from the stem surface. The root was laterally compressed, height being 19.5 cm and breadth 10.3 cm at the measuring point. The root system was relatively well attached to the soil with aid of numerous sinker roots, and when at the end of the experiment the tree was pulled down with a winch, the stem broke at the base, and roots were not lifted up.

Fig. 5 shows the experimental arrangement and Fig. 9 the vertical movements in mm, beneath the direction of the wind and velocity in knots, as measured at Helsinki Airport.

The root movement began at wind speeds approximately of 10 knots (3—4 B), depending on wind direction. Wind speeds of over 20 knots (5 B) resulted in general in movements of over 0.5 cm amplitude. As expected, southwestern winds caused the greatest movements, up to 8—9 mm from the resting position. This corresponds inclinations of ca. 3°. From the graph is also seen the importance of gusts to root movements (cf. G l o y n e 1968). Northern and eastern winds caused considerable downward movement, e.g. on June 11, at which time the root was in a continuous movement of 2—3 mm amplitude downwards. In total the amplitude of the movements of the root was about one centimeter. When the root was dug up, there was a distinct cavity around the root, the bottom of which was covered with loose bark sheets. Further from Fig. 9 is seen that the root was approximately 60 % of the time in a definite (over 0.2 mm) movement.

Fig. 10 shows movements of another spruce tree (height 17 m, d.b.h. 32 cm) growing in a drained spruce swamp about 500 m from preceding tree. The tree was surrounded from every direction by trees of equal height. In November, when the soil was not yet frozen, the movements were considerable, but when the soil in December froze, the root movements totally ceased. According to L a i t a k a r i (1929, see also W e r n e r & Å r m a n n 1955) freezing of the soil decreases the susceptibility of trees to windthrow by fixing the roots more steadily into the soil.

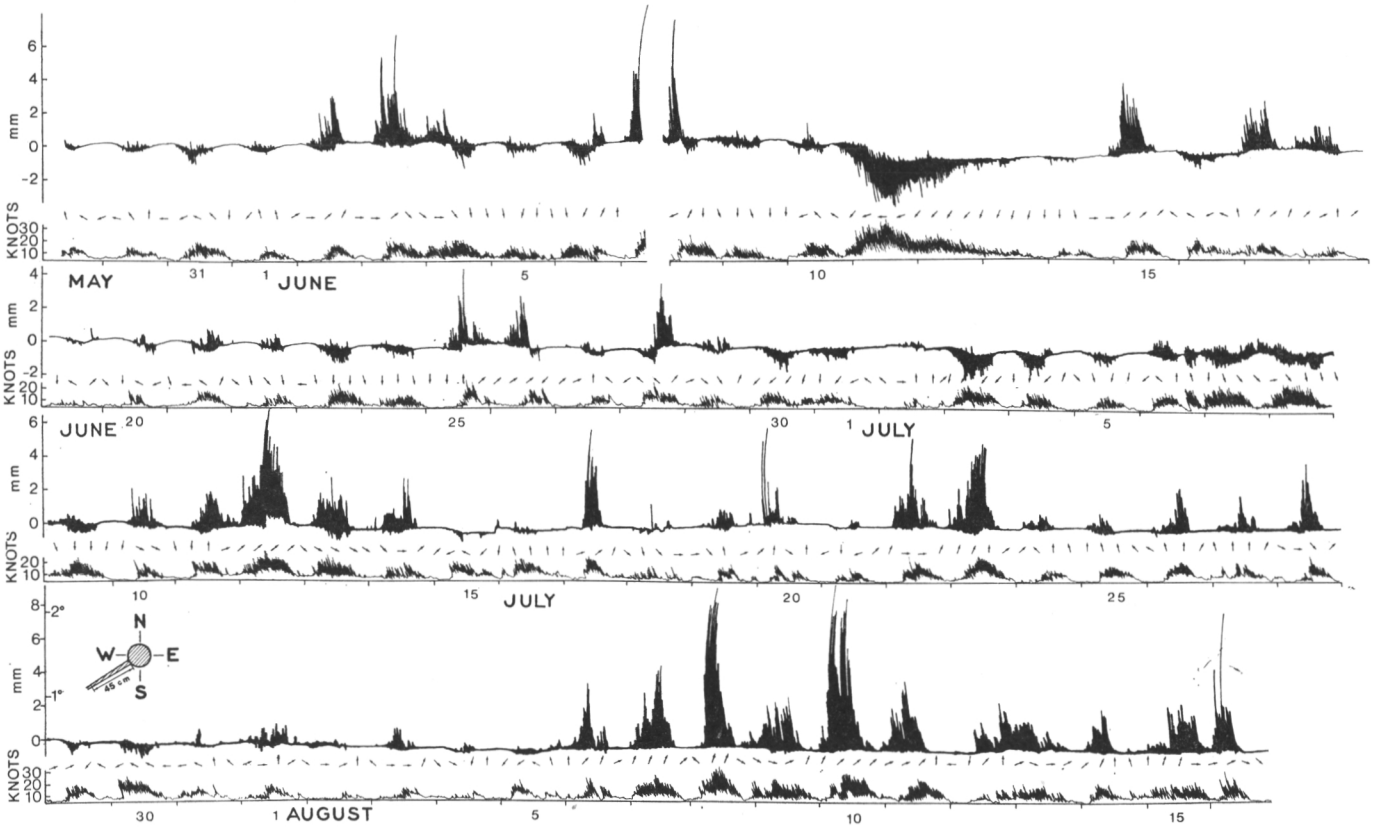

Fig. 9. Vertical movements in mm of a spruce root in summer 1971 (uppermost curves). The tree and the experimental arrangement is seen in Fig. 5. Beneath the direction and the velocity of the wind, as measured at Helsinki Airport at a distance of 1 700 m. Lower left, the position of the root investigated in relation to the points of compass.

Kuva 9. Kuusen juuren pystysuora liike kesällä 1971 (ylin käyrä), sekä tuulen suunta ja nopeus solmuina Helsingin lentoaseman säähavaintoasemalla 1 700 m:n etäisyydellä. Vasemmalla alhaalla juuren sijainti ilmansuuntiin nähden. Koejärjestely ilmenee kuvasta 5.

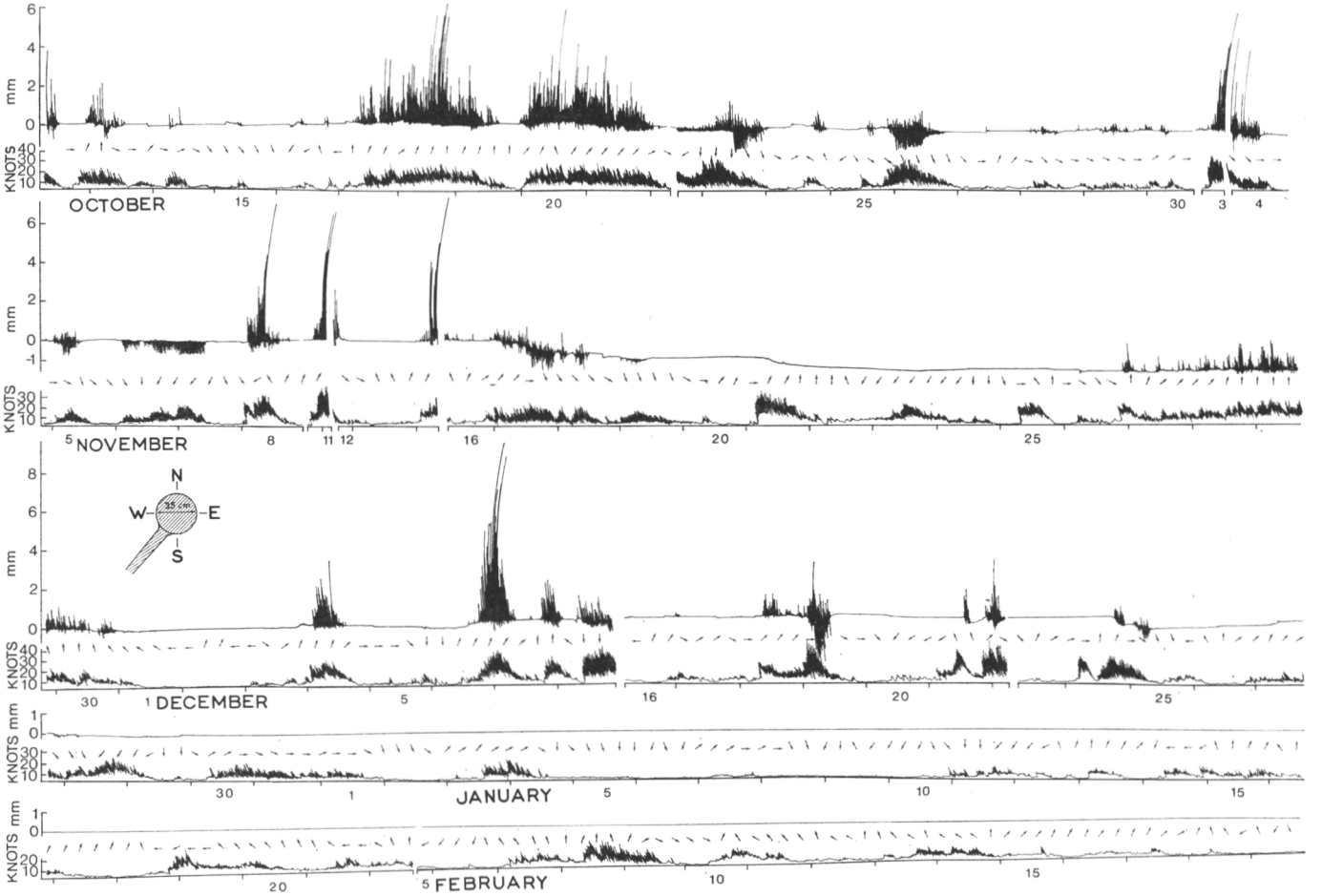

Fig. 10. Vertical movements (mm) of a root of a spruce tree (d.b.h. 35 cm height 17 m), growing in a drained spruce swamp near Helsinki Airport. Upper curve: vertical movements of the root, below the direction and velocity of the wind (in knots), as measured at Helsinki Airport. Freezing of the soil in late November and in January and February caused the cessation of the movements. At centre left the position of the root in relation to the points of compass.

Kuva 10. 17 m korkean ojitetussa korvessa kasvaneen kuusen (d 1.3 35 cm) juuren pystysuorat liikkeet talvella 1971—72. Kuusi kasvoi lähellä Helsingin lentoaseman säähavaintoasemaa. Käyrät ylhäältä: juuren liikkeet, tuulen suunta ja tuulen nopeus solmuina Helsingin lentoaseman säähavaintojen mukaan. Maan jäätyminen marraskuun loppupuolella sekä tammi- ja helmikuussa aiheutti juuren liikkeiden loppumisen. Vasemmalla keskellä juuren sijainti ilmansuuntiin nähden.

23. Observations on tree stability

As the previous observations indicated, there is considerable variability in the attachment of different tree individuals to the soil. Especially spruces on clay soils are sometimes very easily pulled down with only a small force. The main obstacle to the exact assessment of the degree of stability of attachment of the roots is the weight of the crown. On the other hand, short tree stumps are not easily moved. For this reason, the study was carried out by cutting trees at a height of 2 metres from the ground, and pulling this long stump with the aid of a winch, to which a dynamometer was attached. Often movements were readily detected with the bare hands, and the long stump was easy to shake.

Fig. 11 illustrates the results of pulling experiments on decapitated spruce trees. Considerable differences are evident between individual trees.

Fig. 12 shows the results obtained with young pine trees, which were pulled at the same height, the resulting inclination being recorded. The trees were of same age, and their d.b.h. varied within two centimetres. It is seen that some trees are quite loosely attached, so that little force is needed to incline them.

It is evident that there are trees, which are not firmly attached to the soil. This may be due to the following reasons:

1. The tree is growing on a large stone in the soil, on which it cannot become firmly rooted. Such trees were evidently not included in the material.

2. The root system is one-sided, either having developed asymmetrically, or owing to decay or breakages near the stem base. In all the trees pulled, the roots seemed to be evenly distributed, and no special empty sectors were found. However, a through investigation would necessitate digging up the root systems, and this was not undertaken in this study. Thus the

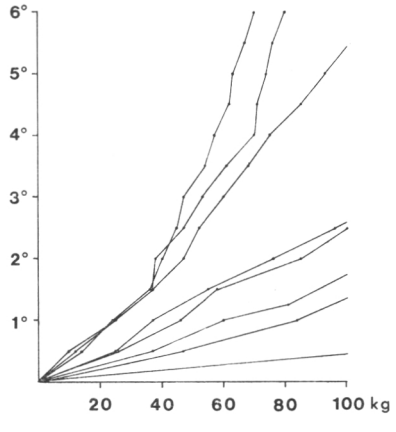

Fig. 11. Spruce trees of approximate same size, d.b.h. 9—11 cm, were cut at the height of 2 m, and the stump was pulled with a winch to inclinations of 1°—6°, and the corresponding power was noted. Loosely attached stumps (rising curve) were readily shaked with hands in the absence of the weight of the crown.

Kuva 11. Kuusia, joiden rinnankorkeusläpimitta oli 9—11 cm, katkaistiin 2 metrin korkeudelta, ja tynkää kallistettiin vinssillä 1°—6°, ja tarvittava voima mitattiin dynamometrillä. Juuristoltaan höltyneitä puita (jyrkästi nouseva käyrä) oli helppo heilauttaa paljain käsin.

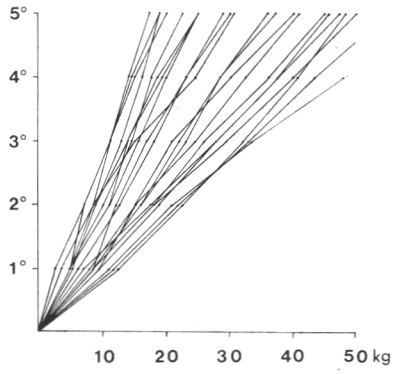

Fig. 12. 20 year old pine saplings, d.b.h. 6.0—6.5 cm, were inclined 1°—5°, and corresponding power was recorded (horizontal axis). Certain trees were fairly loosely attached to the soil (rising curves).
Kuva 12. 20 vuotta vanhoja männyn taimia, rinnankorkeusläpimitta 6.0—6.5 cm, taivutettiin 1°—5°, ja tarvittava voima mitattiin dynamometrillä. Eräät yksilöt olivat hyvin höllästi maassa (jyrkästi nouseva käyrä).

results may have been influenced to some extent by asymmetrical root systems (see also Laitakari 1927 and Faulkner and Malcolm 1972).

3. In peat soil, the root system seems to be looser than in sand soil. On clay soils the roots of spruce are so superficial that the attachment is loosest in this soil group.

4. The main cause of loose attachment seems to be wind sway or snow pressure, which breaks some of the side roots and causes movements in the roots leading to breakage of side or sinker roots. The following observations support this assumption. Some of the easily pulled trees presented in Fig. 12 were known to have been bent by heavy snow pressure to inclinations of 30° from the vertical during the preceding winter. Although they were able to right themselves in the following summer and autumn, the pulling experiments indicated that their root systems had become much weaker than in trees not exposed to snow pressure. An empty space caused by the bending of the stem was often observed in the moss around the bases of these trees due to the movements of the stem.

24. The degree of inclination in tree stems

Except in wind-swept situations, pine and spruce trees grow straight upwards. Consequently all deviations in the position of the trunk from the vertical indicate the effect of some external agency, and if bends and breakages in the stem are excluded, also movements in the root system.

The degree of inclination was determined with an inclinometer constructed from a commercial water level, which was placed on the side of trunk facing

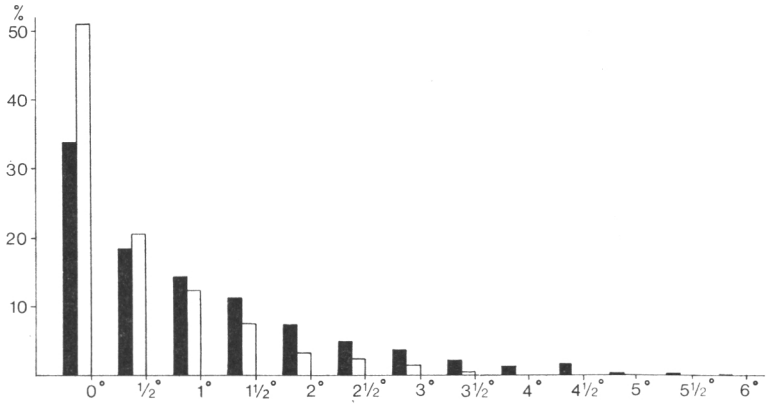

Fig. 13. Angle of inclination from the vertical of stems of 1 779 pines (black columns) and 1 406 spruces (white columns), both groups with d.b.h. over 20 cm.

Kuva 13. 1 779 männyn (mustat pylväät) ja 1 406 kuusen (valkeat pylväät), joiden rinnankorkeusläpimitta oli yli 20 cm, rungon poikkeama pystysuorasta.

the direction of inclination, this being determined by ocular estimation or by a few measurements on different sides of the tree. The measurements were carried out between the heights of 70 cm and 150 cm, and were made with an accuracy of ½ degree. As the stem is more or less conical, in theory, exactly vertical values indicate slightly leaning stems. Measurements were made in experimental forests at Ruotsinkylä, Vesijako, Lapinjärvi and Solböle; the d.b.h. of the stands was over 20 cm, and all stands on peat soils were excluded as well as trees with distinctly curved stems. Fig. 13 shows the inclination of 1 406 spruces and 1 779 pines. A definite inclination, of over 1°, which could be seen without measurements, was observed in 32 % of the pines and 14 % of the spruces. An inclination of over 3° was noted in 5.7 % of the pines and 0.7 % of the spruces.

The measurements indicate that sometime during the life of these trees stem inclinations must have occurred, which presumably resulted in root movements. It was not possible to ascertain in the present investigation whether the roots of the inclined trees had more injuries than those of other trees, but observations made on excavated pine stumps suggest that injuries are very common, in some cases extending over an area of several dm^2. According to Laitakari (1927, 1935) dead roots are common in root systems of pine and birch.

The difference between the tree species evidently depends on several factors. It is possible that the pines were growing in more windswept situations than the spruces, but the difference is also seen in mixed stands. The explanation most probably lies in the structure of the root systems. In the spruce, which has strong surface roots but usually no tap root, the lateral

support seems to be somewhat better developed than in the pine, which is anchored by the deep tap root and thus perhaps more easily inclined. It would be interesting to ascertain whether the inclinations have occurred suddenly during heavy storms, or gradually.

Earlier investigations show that in mountainous situations the amount of leaning trees may be much higher, and the amount of trees inclined more than 5° may exceed 14 % (Fielding 1940).

25. Discussion

The observations reported above show definitely that considerable root movements are regularly caused in forest trees by the bending action of the wind, even at relatively low wind speeds. The movements are not connected with windthrows, and must be regarded as a normal phenomenon in the biology of forests. Their magnitude depends on several factors; if exposition to wind is excluded, these are mainly wind speed, soil material, size of the tree, tree species, and the strength of attachment of the individual root systems.

Although minor movements in loosely attached tree root systems may occur at wind speeds of 2—3 B, measurable movements mostly begin at wind speeds of 4 B and upwards. According to Franssila (1930), in summer in south Finland wind speeds of more than 5 m/sec. prevail for 1 800 hours, and speeds of more than 10 m/sec. about 100 hours. When these data are considered together with those in Figs. 7—11, it can be estimated that in loosely attached spruce roots vertical movements may occur tens of thousands of times every year, in coastal areas or in exposed situations perhaps even over one hundred thousand times.

The magnitude of the movements depends primarily on the soil. On clay and shallow peat soils movements are induced in spruce roots by a 4 Beaufort wind and on the windward side the roots may rise several millimetres, but on till soils on equally exposed sites the movements remain at the 0.1-mm level.

Differences are evident between different tree species and individuals in the same stands. If pine has been able to develop a tap root, its root system is fairly stable, unless, for instance, snow pressure or decay has caused root breakages. The roots of birch also seem to be rather firmly attached, compared with those of spruce.

A film, taken with a speed of 24 pictures per second showed that the velocity of the vertical movements of a spruce root at a distance of 50 cm from the stem in a wind of about 5 Beaufort was approximately 2—3 mm per second.

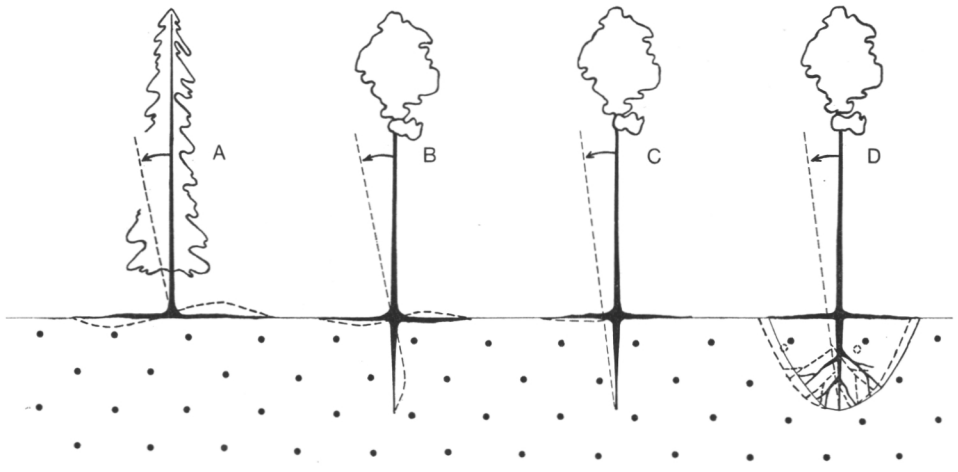

Fig. 14. Schematic picture of different possible types of root system movements in spruce and pine. Dotted lines: bent position of stem and roots. A: Root plate without tap root, rocking motion of horizontal roots. B: Tap root bending in opposite direction to that of stem. C: Tap root moving in same direction as stem, surface roots moving mainly horizontally. D: A large mass of soil moving together with the root system.

Kuva 14. Kaavamainen kuva männyn ja kuusen juuristojen liikkeiden eri tyypeistä. A: Kuusen juuristolevy, jonka liikkeet ensi sijassa pystysuoria. B: Pääjuuri liikkuu vetoon (tuuleen) nähden päinvastaiseen suuntaan. C: Pääjuuri liikkuu samaan suuntaan kuin runko, ja pintajuuret etupäässä vaakasuorassa suunnassa. D: Maapaakku liikkuu juuriston mukana.

In trees with small crowns and short stems the bending action of the wind is much less pronounced and thus relatively weak root systems may anchor small trees firmly. However, in peat soils, the root systems of 3—4 m high spruce trees are often moved significantly by the wind, even in closed stands. The higher the tree grows, the greater becomes its weight and also the bending force. According to S a m s e t (1962), spruce trees with 35—40 cm d.b.h. and a height of over 20 m weigh about one ton. In many cases the central parts of the root plate of spruce have almost no contact with the mineral soil, as is seen in the root systems of windthrows, where broken sinker roots are only rarely seen at the stem base. In these root systems, the bending power of the crown must place a very great strain on the thinner outer parts of the surface roots.

On the basis of the observations presented above, four types of root system movements can be distinguished (Fig. 14). Especially the three last-named types intergrade to a considerable extent, but they are provisionally treated as separate types.

1. *Root-plate movements* (Fig. 14, A). In spruce on clay and peat soils vertical roots are usually completely absent near the stem base. The root plate moves easily in the wind, and, since the flattening of the main lateral

side roots makes them resistant to bending, the main stress is transmitted to the thinner roots at a distance of 1—3 m from the stem base. The vertical movement in these lateral roots is very pronounced.

2. *Movements of tap-rooted systems, with tap root moving in opposite direction to that of bending stem* (Fig. 14, B). These have frequently been observed in pine. The lateral roots hold the root and stem base so firmly attached to the soil that the strong tap root moves in the soil. The main stress is transmitted to the tap root, especially to the bending end, and the bases of the main lateral roots, which move horizontally as well as vertically. The movements are much smaller than in the preceding type.

3. *Movements of tap-rooted systems, with tap root moving in same direction as stem and side roots moving more horizontally than vertically* (Fig. 14, C). The tap root is evidently attached so rigidly to the soil that movement of type 2 does not occur, and the lateral attachment is looser. This has been observed on several occasions in pine. Movements of the surface roots are mainly horizontal.

4. *Movements of the whole root — soil mass* (Fig. 14, D). The experiments described on p. 11 and observations on wind-thrown trees indicate that, when the root system moves, considerable amounts of soil, sand, and stones follow with the roots. In pines blown down by the wind, up to one cubic metre of soil can be torn up with the root systems, and this soil mass evidently moves together with the roots when the stem is bent less. The main abrasive action occurs at the outer parts of the root system.

Type 1 occurs chiefly in spruce in clay and peat soils, and types 2—4 in pine as well as in spruce in sandy and till soils. Future investigations may show that all these last three movements may occur simultaneously in the same root system.

An additional type of tree root movement may be caused by the weight of the stem and crown, which, according to several investigators (L i e s e 1926, F r i t z s c h e 1933, P r y o r 1937, F a y l e 1968, see also Fig. 17), may push the stem base deeper into the soil. This can be seen in the position of the pith in the roots and remains of twigs below the soil surface. The rocking movements described in this paper may effectively contribute to this process.

The occurrence of these types of root system movements in pine is also suggested by observations on wind-thrown trees. In autumn 1970, several extensive areas with windthrows in central Finland were investigated, among which one in Korpilahti contained several thousand fallen pine trees. In many of the trees clear indications were found of movements of type 2.

The tap root had made a semicircular movement and lifted up considerable amounts of surface soil and litter, and the stem base was in its original position. There were also trees whose root systems suggested movements of type 3.

In the wind-thrown pine trees, considerable amounts of sand were often attached to the root system as in type 4. Brown roots were seen on the surface of the sand mass. It seems likely that in strong winds the soil and sand mass moves slightly and erodes thinner roots, which evidently affects their morphology. On the other hand, it may contribute to the penetration of roots into tightly packed soil.

3. BIOLOGICAL EFFECTS OF WIND-INDUCED ROOT MOVEMENTS ON ROOT MORPHOLOGY AND ON FOREST HUMUS LAYERS

31. Effects of root movements on external root morphology

The observations reported above on moving spruce roots indicated that during windy days the secondary side roots originating from moving main lateral roots are in almost continuous bending motion. As estimated above, during one year some tens of thousands of bending movements may occur in the side roots and thinner parts of the main lateral roots. The stress is evidently greatest in those parts of the roots where the movements are largest, viz. about 50—150 cm from the stem on the windward side, the distance depending on the thickness of the roots and on the size of the tree. If the root systems of spruce and pine are investigated for this purpose, abundant morphological features, including injuries, can easily be found which can be interpreted as results of root movements.

311. Thickening of bark on bases of side roots and formation of collars

The bases of moving side roots often display thickenings, which sometimes take the shape of a collar. In pine, they may be shaped like an onion, or have several deep circular furrows (Fig. 15). In spruce, thickening is also evident at the bases of secondary side roots. The thickening of the bark is very conspicuous in cross sections.

In branch and root angles folds of bark are mainly due to a secondary increase in thickness (B ö h l m a n 1970), but, in the opinion of the author, this phenomenon cannot cover all the observed bark structures at the bases of thinner side roots. Especially those in spruce at the bases of thick surface roots with moving parent roots suggest stimulation by root bending at least as a contributory factor.

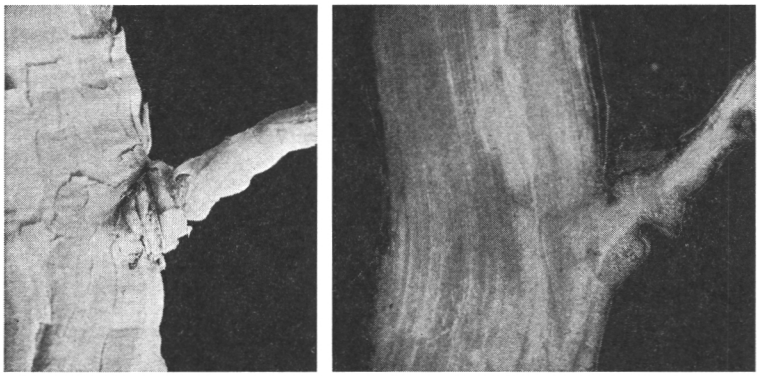

Fig. 15. Horizontal surface roots of pine with thickened bark and collars at the bending points.

Kuva 15. Vaakasuorassa olevia männyn pintajuuria, joiden kaarna paksuuntunut taivutuksen alaiseksi joutuneilla kohdilla.

312. Broken or twisted roots and fascicules of rootlets

The sides of moving spruce roots often show a great number of dead stumps of secondary roots (Fig. 16), which are probably at least partly due to the movements caused by wind sway.

In root systems of spruce, especially in thinner roots, there are usually abundant small fascicules of rootlets. Sections usually show that the end of the original root has died, and a fascicule of adventitious rootlets has formed above the dead part, which regeneration process Wilson (1970)

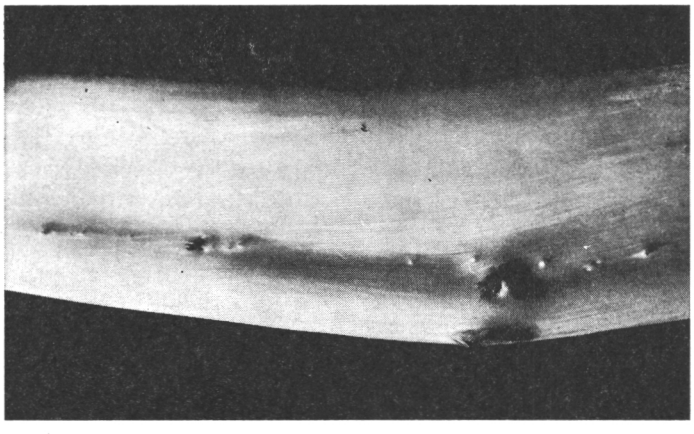

Fig. 16. Debarked horizontal surface root of spruce, showing several broken side roots and one eroded spot.

Kuva 16. Kuusen vaakasuora juuri, jossa katkenneita sivujuuria sekä hankautuma.

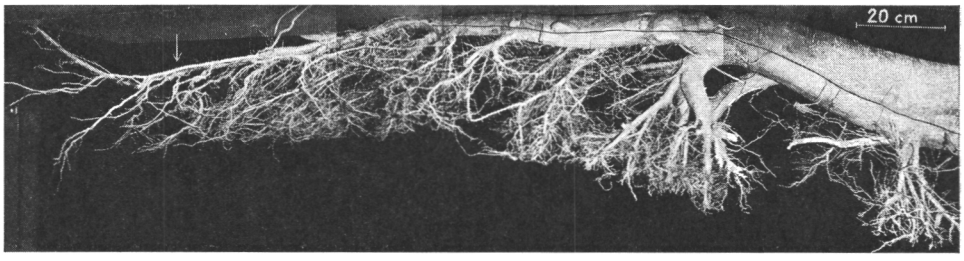

Fig. 17. Root from a wind-blown spruce on shallow peat soil. Note conical sinker roots with fascicules of thinner roots and no broken roots from the actual fall. Black line indicates the position of the pith, which indicates that the weight of the stem has evidently pushed the root base deeper into the peat.

Kuva 17. Ohutturpeisessa korvessa kasvaneen ja tuulen kaataman kuusen juuri. Huomaa kartiomaiset pystysuorat juuret, joissa on runsaasti juurikimppuja, mutta ei kaatumisesta peräisin olevia katkeamia. Musta viiva kuvaa juuren ytimen sijaintia, mikä osoittaa rungon painon työntäneen juurenniskaa syvemmälle turpeeseen.

and Horsley (1971) have described. In the root depicted in Fig. 17, there were about 100—120 distinct fascicules each with one dead central tip. Most of the fascicules were situated at the lower parts of the root, where the peat layer bordered on mineral soil. Although the root is from a wind-blown tree, the breakages must have occurred several years earlier than the actual blow-down. The root systems of wind-blown spruces generally show large numbers of fascicules of this type at the lower surface of the root plate.

Several explanations have been suggested for the death of the root tips. The most widely accepted is that of Hartig (1882), who attributes death to excessive moisture and lack of ventilation in peat and raw humus soils. Recently Orlov (1965, see also Paavilainen 1966, Veretennikov 1968, Lähde 1969, Sutton 1969 and Gill 1970) has emphasized the great sensitivity of roots of pine, spruce and birch to anaerobic conditions. His observations, in both the field and the laboratory, indicate that two days' exposure to anaerobic conditions in summer, is sufficient to injure the roots.

The death of tree roots has also been attributed to drought in summer (Graebner 1909 and 1920), and, according to extensive measurements of Ladefoged (1939), dry periods in summer markedly retard root growth.

Other factors producing root breakages, such as animal (rodents) and human activity (logging operations) as well as movements due to frost heaving (Priehäusser 1939, Hütte 1967), are evidently difficult to separate from the above causes.

Within the framework of the present study it was impossible to determine the exact cause of the death of root tips resulting in the formation of root

fascicules, but the overwhelming impression was that one of the chief factors may be the rocking movement of root systems due to wind sway. As pointed out above, many of the dead root tips are situated at the border between the humus or peat layer and the mineral soil (see p. 40 and Fig. 34), and it is evident that when a rocking movement has been initiated by the bending tree stem, the roots will be liable to break at this border. Primarily the anaerobic conditions in peat and waterlogged soils may be responsible for the inability of roots to grow downwards, which is accentuated by root movements. In addition, there are many features in the external appearence of roots in the root systems of wind-blown spruces, which are impossible to understand without supposing that movements have taken place. The root morphology depicted in Fig. 18 may chiefly be attributed to root movements, which are responsible for the form of the spirally wound, conically thickened side roots, and the abundant breaks in the thinner roots. Fig. 19 shows a vertical root, the lower end of which has evidently been moving continuously up and down against the mineral soil, with the result that the side roots have been bent upwards and downward growth has ceased. The

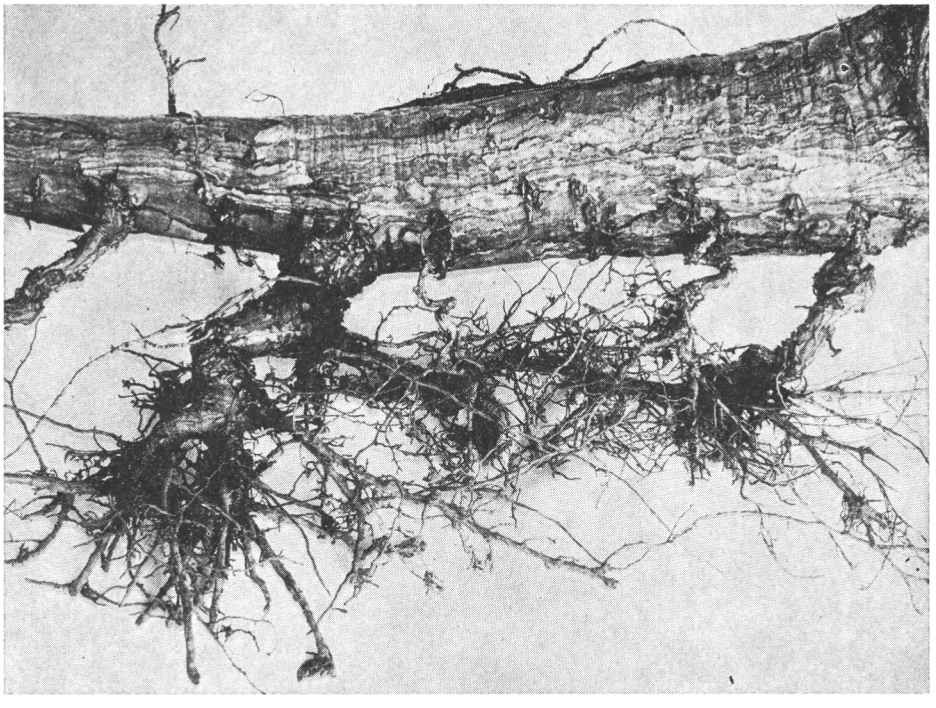

Fig. 18. Typical root morphology from a spruce with a moving root system. Sinker roots conical or spirally wound, and with abundant fascicules of rootlets.

Kuva 18. Tyypillinen kuusen voimakkaasti liikkuvan juuren ulkonäkö. Alaspäiset juuret kartiomaisia tai spiraalikierteisiä ja niissä juurikimppuja.

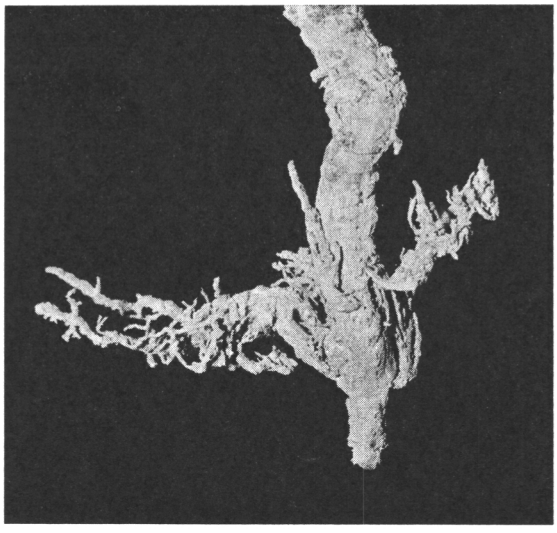

Fig. 19. Vertical root of spruce from a wind-blown root system. The side roots have been bent upwards and the root tip killed by rocking movement before the actual blow-down.

Kuva 19. Alaspäinen juuri tuulen kaataman kuusen juuristosta. Sivujuuret taipuneet ylöspäin ja juuren kärki kuollut ennen kaatumista juuriston hakkaavan liikkeen johdosta.

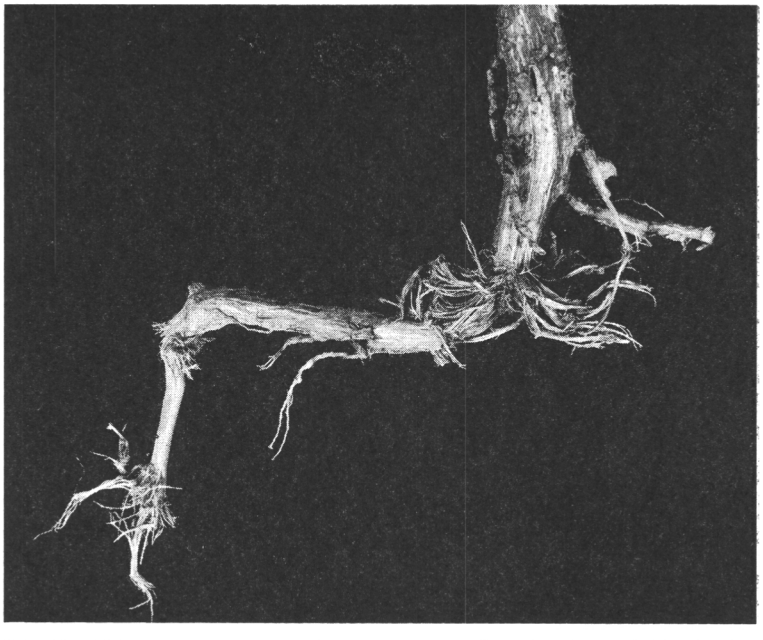

Fig. 20. Sinker root from wind-blown spruce. The breakages indicate that vertical rocking movement occurred in the root system before the actual blow-down. Tuusula, Ruotsinkylä, January 1971.

Kuva 20. Alaspäinen juuri tuulen kaataman kuusen juuristosta. Murtumat osoittavat, että juuristossa on esiintynyt heiluvaa liikettä ennen varsinaista kaatumista. Tuusula, Ruotsinkylä, tammikuu 1971.

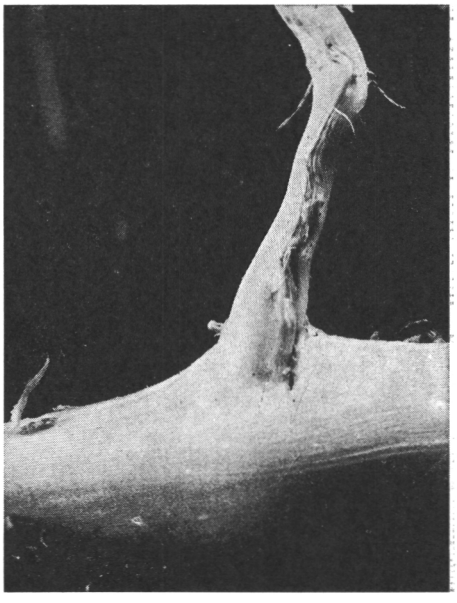

Fig. 21. Base of a side root of pine exposed to longitudinal movements, with injuries on the bent part. Natural size.

Kuva 21. Männyn sivujuuren tyvi, johon on kohdistunut pitkittäissuuntainen liike. Taipuneessa kohdassa vioitus.

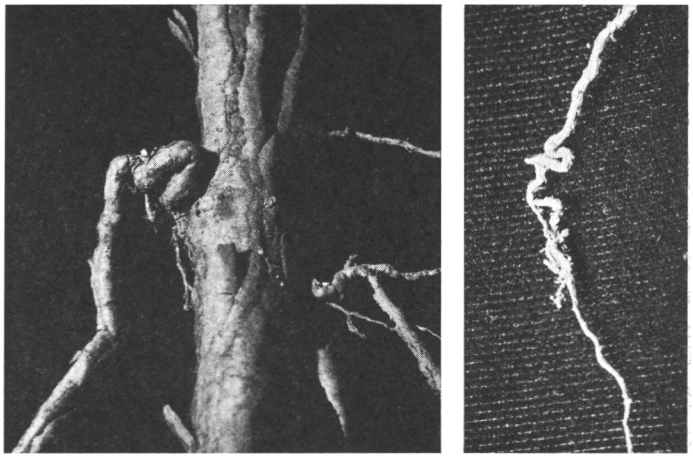

Fig. 22. Left: surface root of pine, which has been exposed to longitudinal movement; the base of the side root is strongly bent. Right: thin vertical root from a moving spruce root system; the movement has taken place at the spirally twisted part. About natural size.

Kuva 22. Vasemmalla männyn pintajuuri, joka liikkunut pitkittäissuuntaisesti, mikä ilmeisesti aiheuttanut sivujuuren tyven epämuodostumisen. Oikealla ohut kuusen alaspäinen juuri liikkuvasta juuristosta. Liike tapahtunut spiraalikierteisessä osassa.

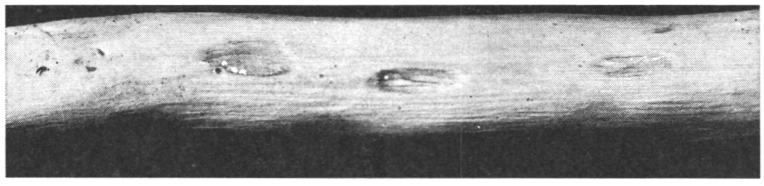

Fig. 23. Resin pockets in a spruce root, exposed to movements in previous winter, depited in Fig. 31. June 1971.

Kuva 23. Pihkaonteloita kuusen juuressa, joka edellisenä talvena joutunut tuulen taivutuksen alaiseksi (esittää kuvan 31 juuria). Kesäkuu 1971.

root systems of wind-thrown spruces often show numerous roots of this type, or roots totally lacking side roots, or broken roots (Fig. 20). The injuries must have taken place before the actual blow-down, as no fresh wounds are evident.

The phenomenon of the death of thinner roots seems to be so common in Finnish forests (see also Laitakari 1927, Sirén 1950, 1955 p. 149, and Kalela 1955) that it badly needs a more detailed study.

When the roots exposed to the rocking motion are debarked at the places where the stress is evidently greatest, at the base of the roots, distinct injuries are often apparent (Fig. 21), and the fibrils are seen to be strongly twisted. These injuries are so common that it seems impossible to attribute them to other causes, e.g. to insects or to other mechanical factors. In addition, it is interesting to note that when a secondary side root is bent, the bending takes place in many cases at the base of the root, and not in the thinner younger parts, as would be expected in normally growing roots.

When the spruce root plate moves, a cavity is often formed in the soil, which growing roots evidently have difficulty in traversing. Thinner roots may grow across it, mainly in places where the movement is smaller, i.e. at the borders of the root plate, and then show a distinct, spirally twisted structure (Fig. 22). The same structure is also visible in the thinner parts of main lateral roots bent by wind action (Fig. 17). In pine roots where movements are largely horizontal, similar structures are found at the bases of secondary side roots (Fig. 22).

Roots exposed to movements in winter 1969—1970 depicted in Fig. 31, were found to contain abundantly resin pockets (Fig. 23) in summer 1970.

313. Stunted ends of sinker roots of pine

Deeply situated ends of sinker roots of pine are often conspicuously worn, and in most cases lack side roots (Fig. 24). A few centimetres above the tip the root may be several centimetres thick and have up to twenty

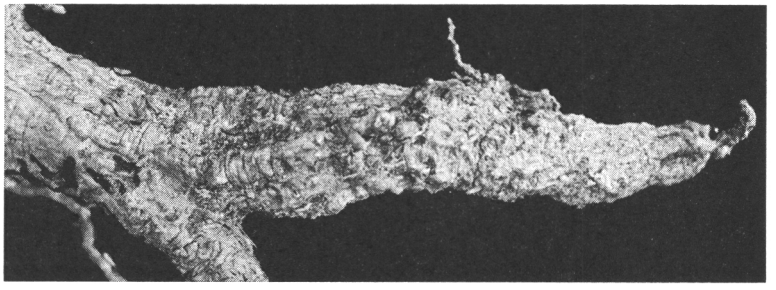

Fig. 24. Stunted root of wind-blown pine from a depth of 40—50 cm in sandy soil. Korpilahti, August 1970.

Kuva 24. Typistynyt männyn juuren kärki noin 40—50 cm:n syvyydestä hiekkamaassa. Korpilahti, elokuu 1970.

annual rings. The external form can be explained to some extent by the presence of less penetrable soil layers at the depth in question, but, in view of the shaking action of sand and the movements of the tap root observed when wind bends the stems, wind action can also be suggested as one of the causes. This type of root develops only occasionally, and probably only in trees in which the sinker roots have been weakened by the swaying of the stem and the tap root has begun to move, evidently leading to a considerable decline in the additional branching and attachment of the roots. As a rule, no major injuries are visible in the external or internal structure of the roots of this type.

314. Eccentric growth of lateral roots

In moving root systems, especially in spruce in clay and peat soils, eccentric radial growth of the main lateral roots is very conspicuous. It is often suggested that this asymmetric growth is connected with root bending and movements (L a i t a k a r i 1927, see review by F a y l e 1968). According to J a c o b s (1936, 1939), the diameter growth in general seems to be connected with bending of the stem, as the prevention of the sway of tree stems causes a marked reduction in diameter growth of the lower part of the bole. In the present investigation, ocular estimation showed an evident correlation between the amount of vertical movements and eccentric growth of spruce roots. If growing in sandy soil, spruces had very strongly attached and rounded roots. In peat and clay soils, the roots were flattened and moved readily in the wind. In addition, cross sections of such roots often revealed that radial growth is at first very regular, and the annual rings make it possible to determine the year when eccentric growth set in

(see illustrations in Rigg and Harrar 1931). This question needs additional investigation, but it seems that root movements may play a considerable role in the initiation of eccentric growth.

315. Exfoliate bark of moving roots

As is well known, the root bark of spruce and pine is strongly exfoliate. In view of recurrent rubbing against mineral soil particles, this property is of definite advantage, as the friction takes place mainly between the bark scales.

Although not all the above morphological features can be attributed exclusively to root movements, they are so conspicuous, e.g. when the root system of a wind-blown spruce is studied that it is strange that some of them have escaped the attention of students of root morphology. The present observations indicate that root movements induced by the wind have a considerable effect on external root morphology.

32. Anatomical peculiarities in roots exposed to wind-induced movements

In addition to changes in external root morphology, roots subjected to recurrent wind-induced movement evidently show a number of anatomical aberrations from normal structure.

Uneven radial growth during the first years. In the roots of conifers, radial growth starts from the protoxylem, which is situated between primary resin channels, usually two in number in Scotch pine and Norway spruce. In normal roots, these resin channels become surrounded by phloem as early as in the first year, the annual growth being regular.

In lateral roots which are exposed to rocking movements, radial growth is considerably disturbed in the vicinity of the resin channels, and in pine, it is often seen to have begun only after 3—5 years. Consequently there may be up to 5 annual rings less in the lateral parts than in the upper and lower parts. This phenomenon has already been noted by Brown (1915), although he did not connect it with root movements.

Irregular shape of resin ducts in cross sections. In moving roots, the resin ducts are generally enlarged in the radial direction. This is not connected with duct branching and the enlargement always occurs outwards, often being accompanied by irregularities in wood formation (Fig. 25).

Increased amount of medullary rays. As in Fig. 26, cross sections of moving roots usually show the medullary rays to be more numerous and filled with starch and other substances.

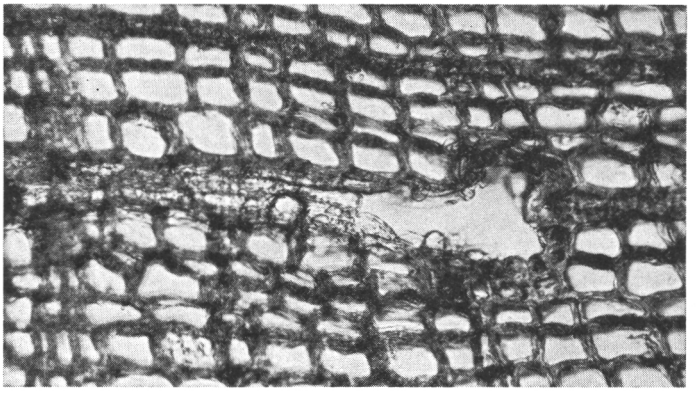

Fig. 25. Resin duct from a moving pine root.
Kuva 25. Pihkatiehyt taivutuksen alaiseksi joutuneesta männyn juuresta.

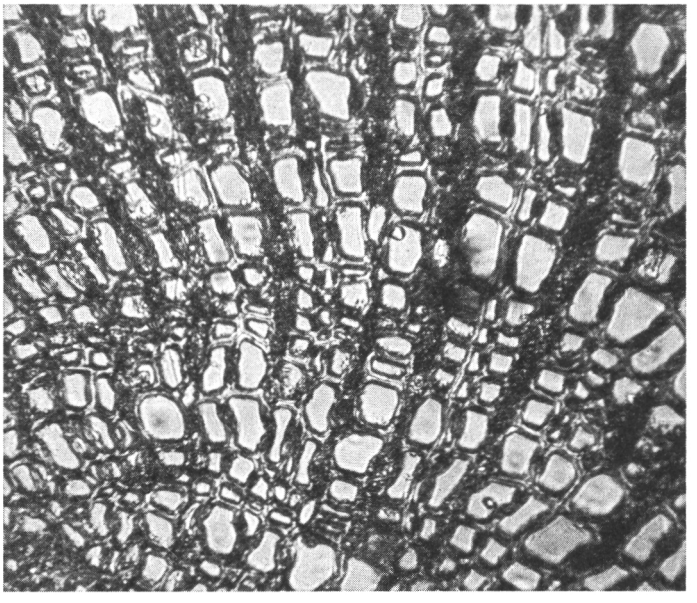

Fig. 26. Cross section of a spruce root exposed to wind movements. Note abundant medullary rays.
Kuva 26. Tuulen aiheuttaman taivutuksen alaiseksi joutuneen kuusen juuren poikkileikkaus.

Form of tracheids. When a root is macerated in Jeffrey's solution (chromic and nitric acids), the tracheids are often seen to be filled with resin-like substances, and the spiral twisting of wall fibrils is more conspicuous than in normal wood (Fig. 27). The tracheids somewhat resemble those in reaction wood.

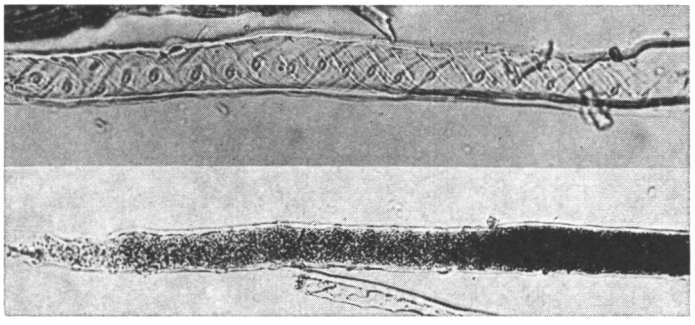

Fig. 27. Tracheids of *Picea abies* from a side root exposed to rocking movements, showing distinctly fibrillose walls and resinlike contents.
Kuva 27. Trakeideja tuulen aiheuttaman taivutuksen alaiseksi joutuneesta kuusen juuresta.

M o h l observed as far back as in 1862 that in conifer roots the first 10—16 annual rings have less summer wood, and that younger roots are consequently more easily bent than older roots, which contain more summer wood and are more brittle. The effect of pull and pressure on woody tissue has many morphogenetic effects (K ü s t e r 1916), including the denser occurrence of pores in tracheids, thinner cell walls and a smaller degree of lignification.

The variation of the length of tracheids in the first annual rings of conifer roots has been demonstrated many times since it was first noted in 1872 by S a n i o. The length increases up to the 8th—13th year. It may be that root movements play a certain retarding role in this process until the root is thick enough to resist movement by the wind. Irregularities in the shape of tracheids are visible in moving roots, and the movements possibly disturb normal tracheid development.

33. Correlation of root injuries with stem inclinations

As pointed out above, it is not always possible to find out the cause of root breakages which have taken place many years earlier. However, indirect information may be obtained in the following way. The date of the breakage can usually be estimated from the number of annual rings in the healingover surface. On the other hand, if the stem is inclined more or less permanently, compression (reaction) wood develops in the corresponding annual ring, which can be identified by the darker colour and the round cross sections of the tracheid cavities. If these two dates fall within the same year, and, in addition, the direction of the bending agrees with the sites of breakage in the root system, there is justification for the assumption that the bending

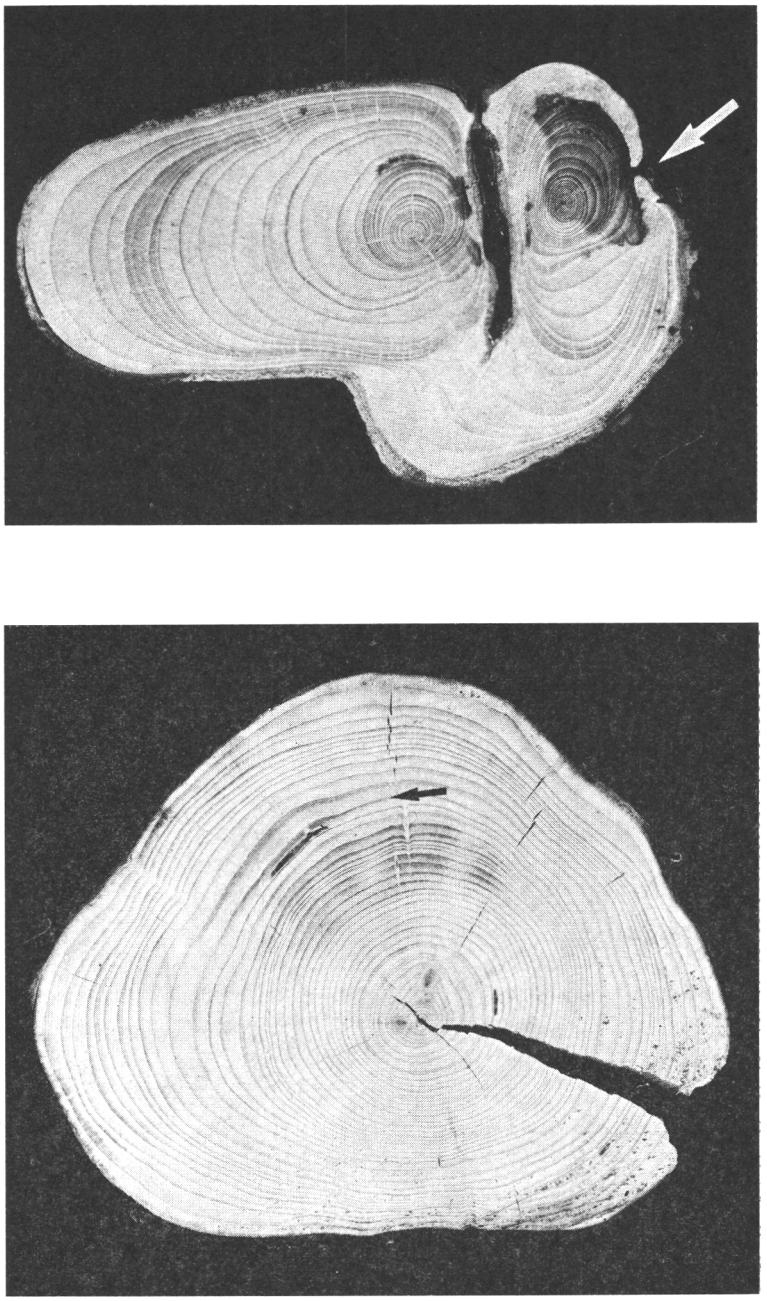

Fig. 28. Spruce root with injury dating back 12 years (white arrow), and stem of the same tree with reaction wood and a resin cavity in the corresponding annual ring.

Kuva 28. Poikkileikkaus kuusen juuresta, joka on vioittunut 12 vuotta sitten (nuoli) sekä saman puun rungon poikkileikkaus, jossa vastaavassa vuosilustossa reaktiopuuta sekä pihkaontelo.

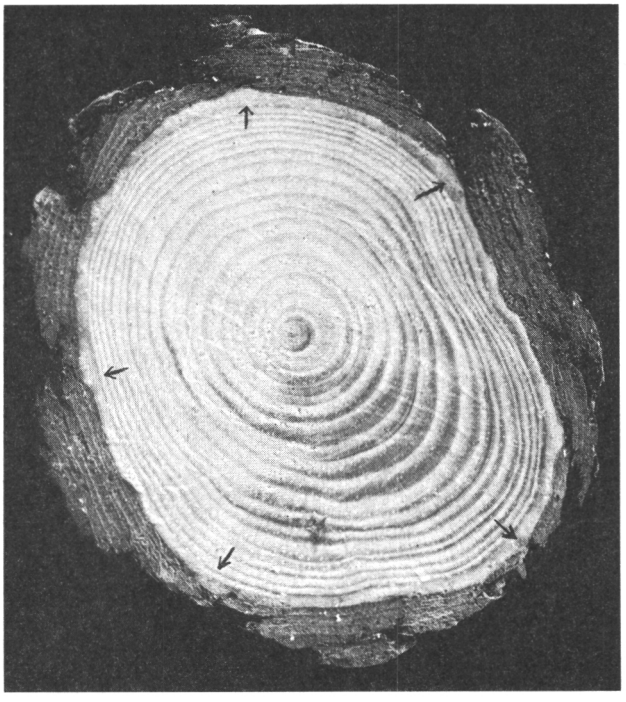

Fig. 29. Stem base of a snow-bent pine sapling. Arrows indicate places where there is practically no bark. Note numerous bark rings. Tuusula, Ruotsinkylä, June 1970.

Kuva 29. Lumen taivuttaman männyntaimen tyven poikkileikkaus. Nuolet osoittavat paikkoja, joista kaarna lähes kokonaan puuttuu. Tuusula, Ruotsinkylä, kesäkuu 1970.

of the stem has caused the root breakage. This evidence is of course only circumstantial, but it is one of the few ways in which information on the initial causes of the decay can be obtained several decades afterwards.

In order to test this method, about 25 freshly cut spruce stumps were excavated. Most of them had a diameter of less than 20 cm, partly because of difficulties in excavating larger stumps, partly because the inital stages of possible decay show up better in young breakages. The occurrence of compression wood in the stem was estimated ocularly on finely polished and wetted stump surfaces. One case is illustrated below where root breakages and the initiation of decay can be dated to the same year in which the stem was bent.

Fig. 28 shows photographs of a ca. 45-year-old spruce with root injuries dating back 12 years. The 12th annual ring displays abundant reaction wood and a resin cavity, indicating bending of the stem.

This example suggest that root breakages may be caused by mechanical bending of the stem. In view of the small number of stumps investigated and the fact that temporarily bent stems do not form compression wood, the amount of correlations seem to be remarkably high.

Bending induced in pine saplings by the snow evidently produces a greatly thickened bark layer at the stem base, with fissures penetrating to the phloem. Fig. 29 depicts the stem of a tree which has evidently been repeatedly bent to the ground by snow, the bark is broken at the base and the inner layers are almost exposed. Probably some insects, for instance, *Aradus cinnamomeus*, can suck the phloem better from these fissures than from unbent stems, where the bark is usually continuous. The remarkable regeneration of the phellogen (8 times in 12 years) also suggests strong bending action.

34. Effects of root movements on the humus layer of forest soils

There are indications that tree roots may have a considerable effect on the soil. For instance, rapidly growing trees may cause soil settlement under roads (Croney & Lewis 1949, Barber 1961), mainly owing to changes in moisture of the soil.

Root systems of wind-blown *Picea* show that considerable amounts of humus are moved with the roots, when the tree falls. The same phenomenon takes place on a smaller scale when the stem is only slightly rocked by wind.

In order to determine the extent of the rise, seven dial indicators were attached to aluminium rods, which were forced to a depth of 50 cm in the mineral soil, being placed at distances of 50—150 cm from the tree on the side opposite to the pull. The sensing rods of the dial indicator touched wooden blocks lying on the surface of the humus. The measurements were made in November 1970, when the uppermost 2 cm of the humus layer were frozen. The dial indicators were read from a distance of 1—2 metre, in order to avoid movements caused by the weight of the observer. The results are presented in Fig. 30. The soil rose within a distance of 150 cm from the tree base, and the greatest upward movement took place about 1 metre from the base. The movements are only a few millimetres at average wind speeds, and take place gradually over a large area, and in strong winds the situation is usually complicated by other wind effects so that the rise of the soil is difficult to demonstrate without indicators. Only in exceptional cases it is seen without difficulty, as in Fig. 31, where the hard snow cover is broken by the movements. In certain cases fissures in the snow are seen only during stronger gusts, when the stem was bent, and disappeared almost completely in calmer intervals. After storms of 6—8 B, on 7.—8. 1., 8. 12.

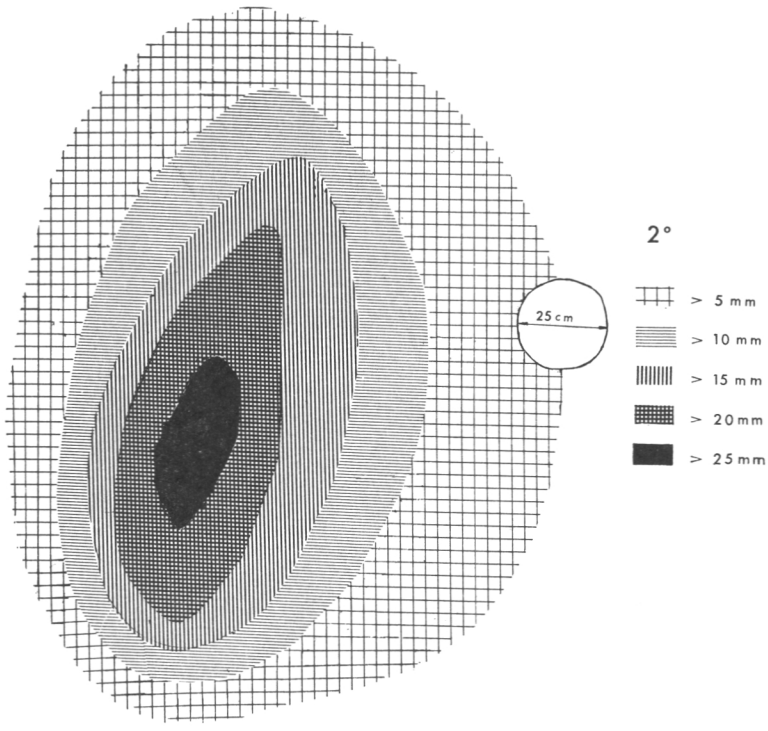

Fig. 30. Rise of surface peat, on a shallow drained spruce swamp, around a spruce tree artificially inclined to the right 2°. The increase of the volume of the peat layer was about 25 litres.
Kuva 30. Pintaturpeen nousu ojitetussa korvessa kuusen ympärillä, jota kallistettiin 2 astetta. Turvekerroksen tilavuuden kasvu noin 25 litraa.

and 19. 12. 1971, fissures in the snow created by upward movements of roots were seen around spruce trees in exposed situations, especially on peat soils, extending up to 3 metres from the tree base. On these occasions, the soil rose up to 5.5 cm.

As observations on root movements in strong winds indicated that the roots may often rise more than 1 cm, it seemed probable that these movements might create cavities in the humus layer or the mineral soil. Earlier Bernbeck (1920, p. 153) and Hütte (1967) supposed that holes and cavities may arise in the humus layer as a result of root activity. Excavations made in the humus surrounding moving spruce roots provided clear evidence of cavities, although there were sometimes difficulties in distinguishing them from holes dug by small rodents. The following method was used to demonstrate cavities formed by wind movements. On a stormy day the maximum vertical movement of a spruce root system in a drained spruce swamp was determined to be 3.2 mm. On the place of the maximum rise, a hole was dug without injuring the roots, and a cavity was revealed, in which vigorous

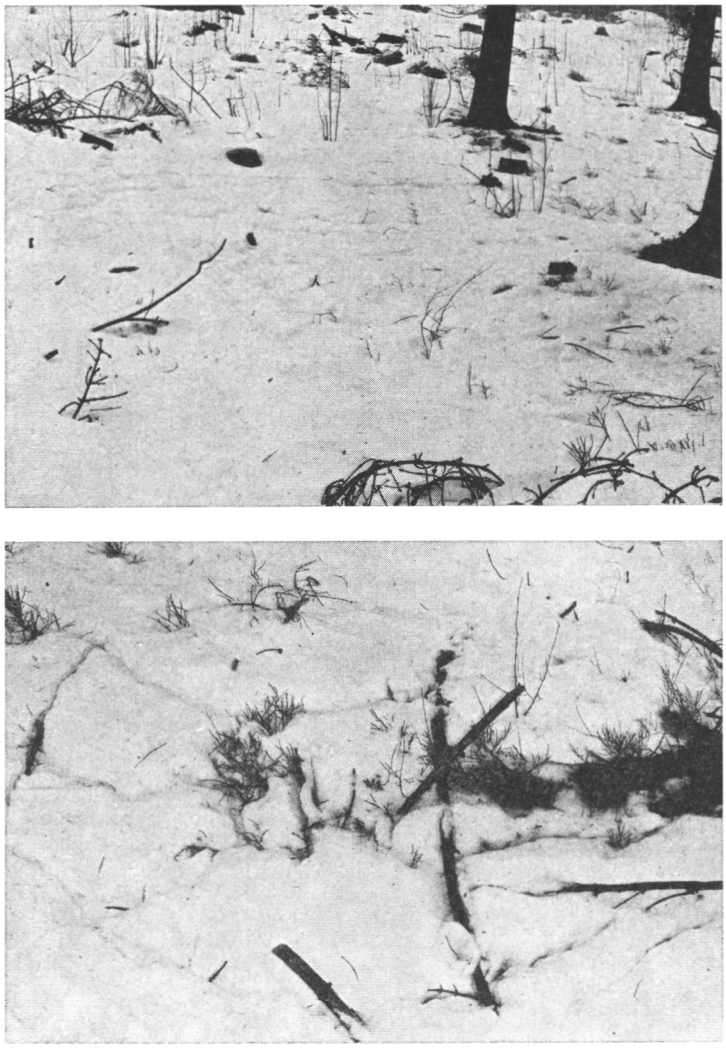

Fig. 31. After a storm (9—10 B) on January 8—9, 1971, fissures and breakages in densely packed snow were visible around spruce trees in exposed situations, especially on peat and clay soils. Extensive (up to 5 cm) vertical root movements and bending have taken place in thinly frozen soil. Tuusula, Ruotsinkylä, 9. 1. 1971.

Kuva 31. 9—10 boforin myrskyn (8.—9. 1. 1971) jälkeen tiiviissä lumessa oli nähtävissä halkeamia kuusten ympärillä varsinkin tuulelle alttiilla turveja savimailla. Ylemmässä kuvassa juuriston pystysuora liike on ollut jäätyneessä maassa noin 5 cm. Tuusula, Ruotsinkylä, 9. 1. 1971.

water movements took place during stronger gusts. These were caused by the movements of the root plate, and on several occasions water was seen forced out of the cavity as it enlarged, water bursted out of it evidently owing to the pressure on the other side of the tree. On the following windless

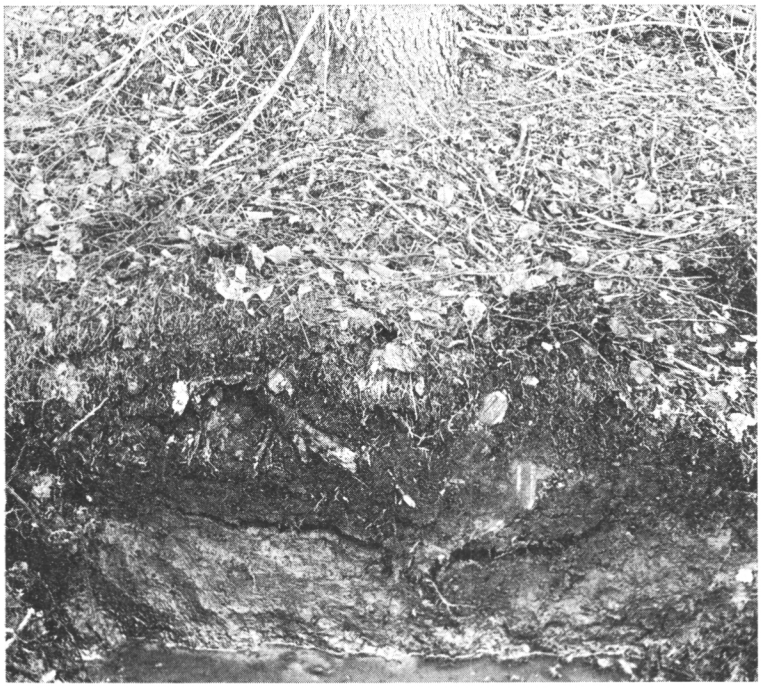

Fig. 32. Formation of a cavity under root system of spruce on clay soil. The picture was taken as follows: On 3. 11. 1971 in a 6—7 B wind, the vertical movements of the root seen in the picture was determined (maximum: 32 mm). A narrow hole was dug without injuring roots, and the presence of cavity was confirmed. On following windless day a trech visible in picture was dug, and the tree inclined artificially to an inclination corresponding to root movements in wind, and evidently cavities as large as in the picture occur in storms.
Kuva 32. Ontelon muodostuminen kuusen juuriston alle savimaalla. Kuva on otettu seuraavasti: 3. 11. 1971 noin 6—7 boforin myrskyssä puun juurten liikkeeksi todettiin 32 mm kuvatulla kohdalla ja lisäksi selvän ontelon muodostuvan juuriston alle. Seuraavana tyynenä päivänä kaivettiin kuvassa näkyvä oja, ja puu kallistettiin juurten liikettä vastaavaan asentoon.

day a trench, shown in Fig. 32 was dug, and the tree inclined artificially to reproduce the root movements observed during the storm. The results indicated that fissures of the type shown in Fig. 34 are repeatedly formed in peat soils during strong winds and storms. The upper and lower sides of the cavity were smooth-walled and showed signs of the eroding activity of the water and the fissure was evidently quite permanent.

Fig. 33 depicts a peat sample from a spruce swamp, which shows a distinct, smooth-walled fissure between upper moving humus in the root plate and the underlying peat. As the spruce, at the base of which the sample was taken, weights about 500—600 kg, the movements of the root plate must have a considerable mixing action on the peat beneath it. Evidently for

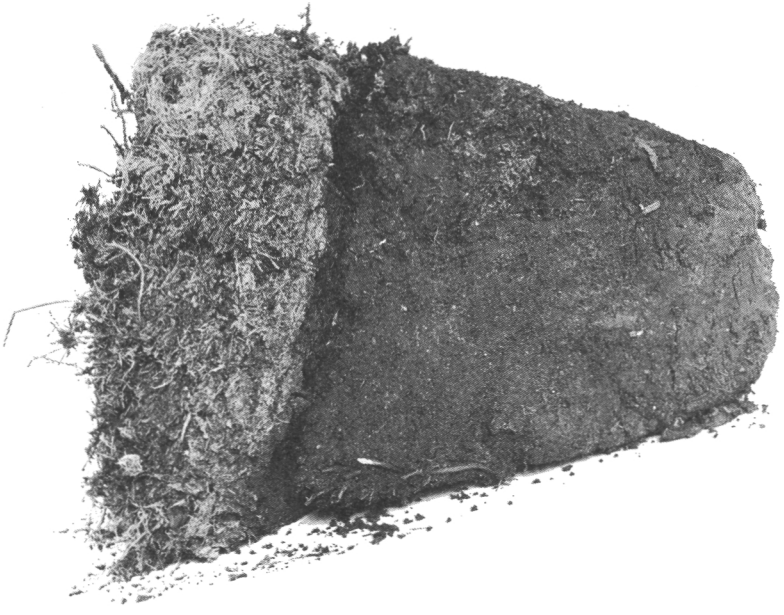

Fig. 33. A piece of peat from a spruce swamp, Tuusula, Ruotsinkylä. In strong winds the upper layer was in a vertical motion of 0.5—1.0 cm, and consists of tree roots, unhumified peat, and living mosses. Under the sharp moving limit peat is in advanced stage of humification, probably due to the compressing action of spruce roots in wind.

Kuva 33. Turvenäyte korvesta, Tuusula, Ruotsinkylä. Kovalla tuulella ylempi kerros, joka muodostuu pääasiassa juurista, elävistä sammalista ja heikosti hajonneesta turpeesta, oli noin 0.5—1.0 cm:n liikkeessä. Alempi kerros pitkälle hajaantuneessa tilassa, osaksi johtuen juurten puristavasta vaikutuksesta tuulessa.

this reason the moving part was unhumified moss humus, while the peat immediately under the limit of the root plate was in an advanced stage of decay. Heikurainen (1960) has emphasized that in drained peatlands one of the factors responsible for the compaction of the peat layer is the weight of the trees, and the movements of the root plates evidently accentuate this effect.

The existence of cavities was also demonstrated by digging a 15—25 cm deep hole at the base of a moving spruce, and placing smoke powder in it. The hole was covered tightly with plastic and aluminium plate and leaves, and the powder was lit. The tree was then rocked and any issuing smoke was observed. The powder used was made by Ilotulitus Oy, Tuusula, and mainly consisted of resins and ammonium chloride. If the humus layer was intact, the issuing smoke was only faintly discernible, but if the humus layer was pierced by vertical holes, the smoke emerged at considerable distances from the hole, when the tree was rocked (Fig. 34). In larger spruces,



Fig. 34. Demonstration of the existence of cavity under the root system of a spruce tree, d.b.h. 10 cm, on clay soil in Tuusula, Katila, November 25, 1970. Smoke powder was placed in a 15-cm-deep hole, indicated by the arrow, covered with plastic and litter, and lit. When the tree was rocked, the smoke generated issued from vertical holes made with an aluminium rod at distances of up to 70 cm.

Kuva 34. Kuusen (läpim. 10 cm) juuriston alle muodostuneen ontelon osoitus. Savupanos sijoitettiin nuolella merkittyyn kohtaan, peitettiin sekä sytytettiin. Kun puuta heilutettiin, savua tuli esiin pystysuorista rei'istä 70 cm:n etäisyyteen saakka.

smoke is issued from under the main lateral roots, at a distance of up to 180 cm, and distances of 50—100 cm were common. If smaller spruce trees were gently shaken, issues of smoke were noted almost throughout the area of the root plate. When a trench was dug about 130 cm from the smoke hole, abundant smoke came from the cavity under the root plate.

These observations indicate that in strong winds cavities are evidently formed in the humus layers under the root plates of spruce trees. This must have some effect on the ventilation of forest humus. If a square metre rises one millimetre, then the volume of the humus layer is increased by one litre, and an equivalent amount of air moves a short distance into the humus. If the increase of volume of the humus layer is calculated from Fig. 30, it is found that at inclinations of 2° the volume of the humus layer around the tree in question increases by about 25 litres. As is seen in Fig. 32, the cavities formed are relatively deep, and consequently considerable amounts of air are sucked through the humus layer. However, part of the air probably moves across the root plate cavity from the other side.

The movement of air occurring when spruce root systems are rocked by the wind was studied in the following way. In December 1970, when the uppermost humus layer was frozen, holes were made with an aluminium rod 1 cm in diameter to a depth of 50—70 cm at the base of the moving

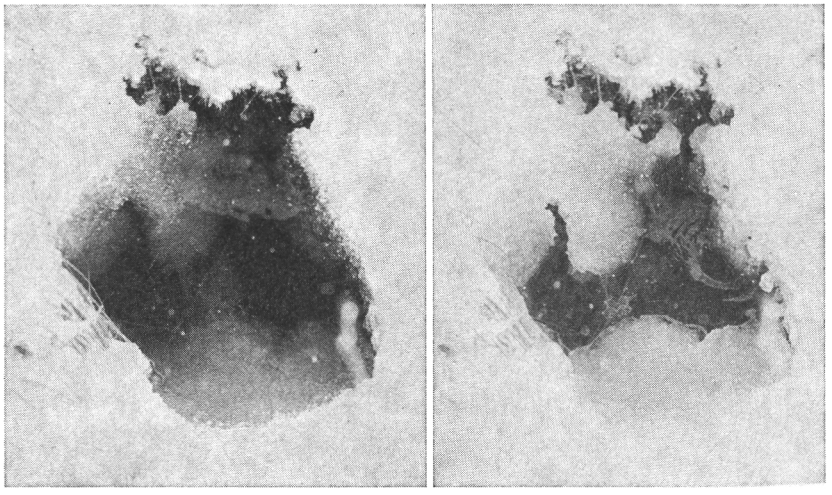

Fig. 35. A small pool in a spruce swamp, were the roots and the humus layer rise and fall in wind gusts of 6—7 B, resulting in changes in water level of a magnitude of 4—6 cm. The photographs were taken at an interval of about two minutes. Tuusula, Ruotsinkylä, December 20, 1970.

Kuva 35. Korvessa oleva lätäkkö, jonka vedenpinta kuusen juuriston liikkeiden johdosta 6—7 boforin puuskaisessa myrskyssä jatkuvasti nousee ja laskee noin 4—6 cm. Kuvat otettu noin kahden minuutin väliajoin. Tuusula, Ruotsinkylä, 20. 12. 1970.

spruce. The sensing element of a Wallac thermo-anemometer was placed in these holes and covered with plastic in order to prevent the disturbing effect of the wind. A distinct flow of air was found at several spruce bases, and the rapidity of the air current fairly often exceeded 0.5 m per second.

The most important factors causing ventilation in forest humus are wind, diffusion, and changes in air pressure and in temperature. It has often been concluded that wind in itself has scarcely any effect in forest stands. However, the ventilation caused by, say, a movement of 3 mm taking place in an area of 1 m^2, down to a depth of 20 cm, 2—3 times a minute, which may easily occur in nature, is very effective compared with the values presented by, e.g. R o m e l l (1922), and this phenomenon must be regarded as one of the most important factors for ventilation in forest soils, especially in spruce swamps. It is possible that the ventilation may become excessive in dry weather in summer, and may result in the drying up of, e.g., young seedlings.

When spruces growing in swamps were rocked distinct movement of soil water was observed in holes dug near the stem base. This was seen on several occasions during strong winds in autumn 1970 in Ruotsinkylä Experimental Forest. Fig. 35 depicts a case where the water level constantly rose and fell ca. 5 cm owing to gusts of wind of 6—7 Beaufort. Thus, in addi-

tion to increased aeration, root movements evidently induce vertical and horizontal circulation of soil water in strong winds. This phenomenon is mentioned by Ramann (1911), Köstler et al. (1968) and Hütte (1968). According to the lastnamed author in storm quantities of soil material are deposited near the windward periphery of the root plate. In spruce swamps, the oxygen content of the soil water is probably higher near the bases of the trees than elsewhere. Although the increased ventilation and soil water movements are only temporary, their effect may be of great magnitude in the case of storms.

35. Significance of root-plate movements of spruce for the spread of *Fomes annosus*

In addition to causing direct root injuries and breakages, wind-induced root movements may promote colonization of roots by root-infecting fungi, e.g. *Fomes annosus*. As is well known, the basidiocarps of this fungus generally lie out of sight in deep moss, often also on the undersurfaces of tree roots.

In addition, the *Fomes annosus* mycelium rapidly forms characteristic conidiophores, when kept in moist conditions (Kallio 1971). The root plate cavities presumably provide suitably moist environments for conidia formation, either in the dead parts of the rocking root system, or on dead wood within the cavity.

It seems that wind-induced movements of spruce roots may effectively promote the liberation of spores from root cavities and the moss layer, in view of the observed flow of air in and out of the root plate cavity (see p. 45).

An attempt was made to study this question in the following way. On a calm day, petri dishes with selective PCNB agar (Kuhlman & Hendrix 1962) were placed, upside down and without lids on a moving spruce root system in a drained spruce swamp. After 5—30 min., the dishes were taken away, and others put in exactly the same places, and the tree rocked manually with a rope to simulate its movements in wind. About six times as many colonies of *Fomes annosus* were recovered from the root system when it was rocked than when it was undisturbed. This experiment suggests that the ubiquitous occurrence of spores of *Fomes annosus* in the air may be partly attributable to root plate movements of spruce.

Air currents produced by root plate movements may enable conidia to colonize small wounds resulting from wind action and rubbing against stones and other roots. If the root plate cavity is partly filled with water, infection is also favoured by the buoyancy of *Fomes annosus* conidia. In experiments carried out at our laboratory, they were kept in water at +4°C, and remained on the surface several months. In general they are

very difficult to bring into suspension with water, being much more buoyant than basidiospores of other wood-decomposing fungi. When stirred, most of the other species sank to the bottom within a few hours.

Thus theoretically it seems that the root plate movements are closely correlated with the dispersal of spores of *Fomes annosus*. In addition, it should be pointed out that besides *Fomes annosus* some other characteristic fungus species occur on wind-blown spruce root systems, e.g. *Flammula scamba*.

36. Discussion

The occurrence of root movements in a tree may have the following effects on tree growth:

1) breakages of roots, 2) initiation of decay, 3) decrease of nutrient uptake, 4) increase of susceptibility to windthrow, and 5) movements of nutrients under the root plate.

The effects chiefly concern spruce, as in mineral soils pine is usually more firmly attached by its tap root.

In spruce saplings less than 3—5 m high, snow pressure seems to be the main root-moving agency, as the effect of wind action is relatively small owing to the small crowns and short stems. Particularly noteworthy is the bending caused by snow in ½—1 ½ m high spruce saplings. It is evidently not very unusual for spruces to be bent for some months to the ground, or at considerable angles, in several different winters. As early a Finnish writer as Blomqvist (1883) drew attention to this factor, claiming that it results in the drying of the bent trees. When the cut surfaces of the bases of spruce stems are investigated, compression wood is found rather regularly in the inner rings, and when the tree becomes thicker compression wood is developed less. Its frequent occurrence must at least partly be attributed to snow pressure. It is clear that when the top of a sapling is bent to the ground, the roots are under great strain and are probably somewhat injured, if the soil is not frozen. Although decay may not be initiated, the vertical roots may be broken, and the attachment to the soil loosened. It is fairly easy to find young undergrowth spruces of this size, the root system of which can be moved with a very small force, even with one finger. It would be interesting to investigate whether the notoriously slow growth of undergrowth spruces (see Siren 1950) can be related to root injuries and to rocking of the root system caused by snow pressure. Besides the effect of snow, the bending effect of the wind becomes more and more evident in spruces, as the crown becomes larger and heavier, and the centre of gravity rises higher.

In this regard, the critical stage in pine is when they reach a height of ½—2 m, when the snow can bend the stem to the ground without breaking it. Planted seedlings seem to be especially susceptible.

The silvicultural goal should evidently be to grow stands in which the rocking movement is not initiated. The critical stage seems to be when the trees attain a height of 2—5 m, when the bending action of the crown is greatly enhanced by the increased in weight and the rapid vertical growth. Means of avoiding the initiation of root movements in tree stands is not definitely known. The risk that rocking will begin in sand, gravel and till soils, is generally small. On the other hand, in clay and shallow peat soils rocking movements are very frequently initiated especially in spruces and evidently increase their susceptibility to basal rot and windthrow, and also to injures in their roots. Early and relatively intense thinning may prove to be the best solution in this case, because in this way the root systems will gradually become adapted to exposed conditions, but the question needs additional investigation.

The short time period of this investigation does not allow a definite answer to the question whether the knowledge of root movements can be used in estimating the susceptibility of a tree to windthrow. As is seen from Fig. 6, it is evident that the root systems of some trees move much more than those of others, and this suggests a greater liability to windthrow. One of the trees in the material of Fig. 6, which had a movement of 10.5 mm, looked more susceptible to windthrow than the others and the sway of its crown seemed on ocular estimation to be larger than in trees with firm attachment to the soil. The appearance of the root base may furnish some indications. Spruces with firmly attached root systems have their roots mostly covered with soil, whereas in moving root systems the roots at the base are visible, and the adjoining roots are much looser than in the former trees.

With the aid of dial indicators, the movements of trees in the wind may be measured in a harmless and relatively simple way. If very exact values for the stability of a tree are required then the individual trees should be pulled with a known force and the corresponding movements recorded; in this way even small inclinations may furnish information on the susceptibility to windthrow. Of course, this method does not indicate hidden breakages or decay in wood or roots, which are important for the stability of trees (Bazzigher & Schmid 1969).

4. SUMMARY

The present investigation was designed to obtain preliminary information on the occurrence, magnitude and biology of movements of tree roots due to the bending action of wind on the stem, and their effects on the forest humus layer.

24 trees were artificially inclined with a winch, and the movements of the roots were recorded with dial indicators (Fig. 1) which register movements of 0.01 mm. In all cases definite root movements, at least in a vertical direction, were observed when the stem was inclined 1° (Table 1).

Root movements in wind were measured with the dial indicators, with a linear motion potentiometer, and with a specially designed recorder (Fig. 5). In wind speeds from 4—5 B upwards, especially in root systems of spruce in clay and peat soils, definite and regular vertical rocking movements were observed. The magnitude varied greatly between individual trees, often being as much as 1 cm in surface roots ½—1 m from the stem base on the windward side of the tree. In pines and spruces growing in sand or till soil the movements were of the magnitude of 0.5—1.0 mm, even in storms, and mostly horizontal.

When these observations were compared with the annual values for the duration of different wind speeds, it was estimated that roots in loosened root systems may yearly make tens of thousands of vertical movements of the magnitude of 0.5—1.0 mm.

On the basis of the above observations, four types of movements of root systems were tentatively distinguished:

1) Root-plate movements, especially in spruce, where the whole root system, which lacks a tap root, moves like a plate and rocks in the wind.

2) Movements in pines with tap roots in which the tap root and the stem move in opposite directions.

3) Movements in pines with tap roots in which the tap root moves in the same direction as the stem, and the surface roots often move more horizontally than vertically.

4) Root plus soil movements, in which a mass of soil attached to the roots moves together with them and the bending action is concentrated in the outer parts of the root system.

In many cases a definite loosening of attachment of root systems was observed. This phenomenon was easily demonstrated by cutting the trees at a height of 1—2 m, and pulling the stump. In the absence of the heavy weight of the crown, the stump was often moved by an extremely small force.

The divergence from a vertical position was examined in 1 779 pine trees and 1 406 spruces. 32 % of the pines and 14 % of the spruces had an

inclination of over 1°, which indicates that root movements must have occurred during the life of these individuals.

The following morphological features in roots are attributed to the action of root movements:

1) Thickening of the bark at the base of moving roots, and formation of collars, and occasional upward orientation of the moving roots.

2) Broken roots and fascicules of roots.

3) Worn ends of vertical roots of pine.

4) Twisting at the base of moving roots and occasiona linjuries at this place.

5) Abnormal formation of wood tracheids in moving parts and development of resin channels.

The causes of eccentric growth of moving roots and exfoliate bark are discussed in relation to root movements.

Several cases are presented where the date of major root injuries, determined from the healed surface, was found to coincide with that of the occurrence of bending of the stem, determined from the formation of compression wood.

The movements of root systems of spruce cause the formation of extensive, up to 5 cm high cavities in the humus layer during stronger winds and storms, especially in clay and peat soils. The presence of these cavities evidently prevents the roots to transverse the cavity, although thin roots may occasionally grow across it, resulting in spirally wound external appearance. Movements increase the ventilation of the humus layer and cause stirring of soil water. It is suggested that these air currents in humus layers promote dispersal of spores of *Fomes annosus* from deeper soil layers.

From the silvicultural point of view, it is important that the initiation of the rocking movements should be prevented as far as possible, as the great bending forces of older crowns make it impossible for the root system to regain stability, if the movements have once begun. The critical stage may be at a height of 1—4 m, when the bending force of the stem increases sharply owing to rapid vertical growth. In many cases, small, extremely slowly growing undergrowth spruces show a rocking root system.

A method is suggested by which the susceptibility of individual trees to windthrow can be evaluated by measurements of root movements made with the aid of dial indicators.

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REFERENCES

Barber, E. S. 1961. Soil settlement caused by tree roots. J. For. 59, 25—26.

Bargmann, B. A. 1904. Die Verteidigung und Sicherung der Wälder gegen die Angriffe und die Gewalt der Stürme, unter besonderer Berücksichtigung der örtlichen Windablenkungen. Allg. Forst- u. Jagdztg. 18, 201—216.

Bazzigher, G. & Schmid, P. 1969. Sturmschaden und Fäule. Schweiz. Z. Forstw. 120 (10), 521—535.

Bernbeck, O. 1920. Wind und Pflanze. Thar. Forst. Jahrb. 71, 130—193.

Blomqvist, A. G. 1883. Finlands trädslag, i forstligt hänseende beskrifna. II. Granen. Finska Forstfören. Medd. 3. 179 pp.

Böhlman, D. 1970. Anatomisch-histologische Untersuchungen im Bereich der Astabzweigung bei Nadel- und Laubbäumen. IV. Allg. Forst- u. Jagdztg. 141, 245—250.

Borggreve, B. 1873. Über die Einwirkung des Sturmes auf die Baumvegetation. Abhandl. herausg. vom naturwiss. Vereine zu Bremen 3, 251—256.

Brown, H. P. 1915. Growth studies in forest trees. Bot. Gaz. 59, 197—241.

Croney, D. & Lewis, W. A. 1949. The effect of vegetation on the settlement of roads. Proc. Conf. on Biology and Civil Engineering, 1948. Institute of Civil Engineers.

Fabricius, L. 1927. Stocküberwallungen. Forstwiss. Centr. 49, 19—26.

Faulkner, M. E. & Malcolm, D. C. 1972. Soil physical factors affecting root morphology and stability of Scots pine on Upland heaths. Forestry 45, 23—36.

Fayle, D. C. F. 1968. Radial growth in tree roots. Univ. of Toronto, Faculty of Forestry Techn. Report No. 9, 183 pp.

Fielding, J. M. 1940. Leans in Monterey pine (*Pinus radiata)* plantations. Aust. For. 5, 21—25.

Franssila, M. 1930. Häufigkeit der verschiedenen Windgeschwindigkeiten am aerologischen Observatorium Ilmala. Soc. Scient. Fenn. Comm. Phys. Math. V: 14, 1—15.

Fraser, A. I. 1962. The soil and roots as factors in tree stability. Forestry 35, 117—127.

Fraser, A. I. & Gardiner, J. B. H. 1967. Rooting and stability in Sitka spruce. Forestry Comm. Bull. 40, 1—23.

Fritzsche, K. 1933. Sturmgefahr und Anpassung. Thar. Forstl. Jahrb. 84, 1—94.

Gill, C. J. 1970. The flooding tolerance of woody species — a review. Forestry Abstracts 31, 671—688.

Gloyne, R. W. 1968. The structure of the wind and its relevance to forestry. Suppl. to Forestry, 1968, 7—19.

Graebner, P. 1909. Beiträge zur Kenntnis nichtparasitärer Pflanzenkrankheiten an forstlichen Gewächsen. 4. Bewurzelungsverhältnisse in Fichtenrohhumus. Zeitschr. f. Forst- u. Jagdwesen. 41, 578—591.

—»— 1920. Lehrbuch der nichtparasitären Pflanzenkrankheiten. Berlin. 333 pp.

Grasso, V. 1965. Characteristic phenomenon of wind in a young pine plantation. Ital. for. mont. 20, 57—62 (in Italian, cited according to Forestry Abstracts 27, p. 86).

Hartig, R. 1882. Lehrbuch der Baumkrankheiten. Berlin. 198 pp.

Heikinheimo, O. 1920. Suomen lumituhoalueet ja niiden metsät. (Ref. Die Schneeschadengebiete in Finnland und ihre Wälder.) Commun. Inst. quaest. forest. Finl. 3, 1—134.

Heikurainen, L. 1955. Rämemänniköiden juuriston rakenne ja kuivatuksen vaikutus siihen. (Ref. Der Wurzellaufbau der Kiefernbestände auf Reisermoorböden und seine Beeinflussung durch die Entwässerung). Acta For. Fenn. 65: 3. 85 pp.

—»— 1960. Metsäojitus ja sen perusteet. Porvoo—Helsinki. 378 pp.

Hermann, R. K. & Petersen, R. G. 1969. Root development and height increment of Ponderosa pines in pumice soils of central Oregon. For. Sci. 15, 226—237.

Horsley, S. B. 1971. Root tip injury and development of the paper birch root system. For. Sci. 17, 341—348.

Hütte, P. 1964. Untersuchungen über den Einfluss des Geländereliefs auf Richtung, Geschwindigkeit und Struktur des Sturmes im Hinblick auf die Sturmgefährgung der Fichte. Diss. Hann.-Münden. 130 pp.

—»— 1967. Die standörtlichen Voraussetzungen der Sturmschäden. Forstwiss. Centralbl. 86, 276—295.

—»— 1968. Experiments on windflow and wind damage in Germany; site and susceptibility of spruce forests to storm damage. Supplement to »Forestry», 1968, 20—27.

Jacobs, M. R. 1936. The effect of wind on trees. Aust. For. 1: 2, 25—32.

—»— 1937. Notes on movements in Eucalypt trunks. Aust. For. 2 (2), 14—18.

—»— 1939. A study of the effect of sway on trees. Commonw. For. Bureau Bull. 26, 1—19.

Kalela, E. K. 1955. Über Veränderungen in den Wurzelverhältnissen der Kiefernbeständen im Laufe der Vegetationsperiode. Acta For. Fenn. 65: 1, 1—42.

Kallio, T. 1971. Incidence of conidiophores of *Fomes annosus* (Fr.) Cooke on the logging waste of spruce (*Picea abies* (L.) Karst.). Acta For. Fenn. 124, 1—9.

Kangas, E. 1946. Kuusikoiden kuivumisesta metsätuho- ja metsänhoidollisena kysymyksenä. (Ref. über die Vertrocknung als Waldkrankheits- und Waldbaufrage). Acta For. Fenn. 52: 5, 1—192.

Keränen, J. 1930. Metsäilmastosta. Maa ja metsä, 4, 540—550.

Kokkonen, P. 1923. Beobachtungen über das Wurzelsystem der Kiefer in Moorböden. Acta For. Fenn. 25, 1—20.

Köstler, J. N. 1962. Untersuchungen zur Wurzelbildung. Allg. Forstzeitschr. 17, 413—417.

Köstler, J. N., Brückner, E. und Bibelriether, H. 1968. Die Wurzeln der Waldbäume. Hamburg und Berlin. 282 pp.

Kuhlman, E. G. and Hendrix, F. F., Jr. 1962. A selective medium for the isolation of *Fomes annosus*. Phytopathology 52, 1310—1312.

Küster, E. 1916. Pathologische Pflanzenanatomie. Jena. 447 pp.

Ladefoged, K. 1939. Untersuchungen über die Periodizität im Ausbruch und Längenwachstum der Wurzeln bei einigen unserer gewöhnlichsten Waldbäume. Forstl. Forsgsv. Danm. 16, 1—256.

Lähde, E. 1969. Biological activity in some natural and drained peat soils with special reference to oxidation-reduction conditions. Acta For. Fenn. 94, 1—69.

Laitakari, E. 1927. Männyn juuristo. Acta For. Fenn. 33: 1, 1—306.
—»— 1929. Über die Fähigkeit der Bäume sich gegen Sturmgefahr zu schützen. Acta For. Fenn. 34. 34, 1—29.
—»— 1930. Metsän ilmastolliset vaarat. Maa ja metsä 4, 551—565.
—»— 1935. Koivun juuristo. Acta For. Fenn. 41: 2, 1—168.
Liese, J. 1926. Beiträge zur Kenntnis des Wurzelsystems der Kiefer (*Pinus silvestris*). Z. Forst- u. Jagdw. 58, 129—181.
Matthes, 1911. Mitteilungen über Bau und Leben der Fichtenwurzeln und Untersuchungen über die Beeinflussung des Wurzelwachstums durch wirtschaftliche Einwirkungen. Allg. Forst- u. Jagdztg. 87, 1—6.
Mohl, H. 1862. Einige anatomische und physiologische Bemerkungen über der Holz der Baumwurzeln. Bot. Zeitung 20, 233—239.
Moore, B. 1933. Unusual wind and soil effects. J. For. 31, 97—98.
Neger, F. W. 1924. Die Krankheiten unserer Waldbäume. Stuttgart. 296 pp.
Orlov, A. Ya. 1965. Ustoichivost kornei derev'ev k izbytku vlagi v pochve. Lesn. Khas. 1965: 2, 9—12.
Paavilainen, E. 1966. On the relationships between the root systems of White birch and Norway spruce and the ground water table. Comm. Inst. For. Fenn. 62: 1.
Peace, T. R. 1962. Pathology of trees and shrubs with special reference to Britain. Oxford. 723 pp.
Priehäusser, G. 1939. Bodenfrost, Bodenentwicklung und Flachwurzeligkeit der Fichte. Forstwiss. Cbl. 61, 381—389.
—»— 1943. Über Fichtenwurzeltfäule, Kronenform und Standort. Forstwiss. Cbl. 65, 259—273.
Pryor, L. D. 1937. Some observations on the roots of *Pinus radiata* in relation to wind resistance. Aust. For. 2, 37—40.
Ramann, E. 1911. Bodenkunde. Dritte Aufl. Berlin. 619 pp.
Redmond, D. R. 1954. Condition of tree rootlets in Nova Scotia following a hurricane. Bi-monthly Progr. Rep., Canada Depart. of Agric., Biol. Div., vol. 10, no. 1, 1.
Reuss, K. 1889. Über die Bewahrung von Windrissen. Cbl. Ges. Forst. 1889, 445.
Rigg, C. B. & Harrar, E. S. 1931. The root systems of trees growing in Sphagnum. Amer. J. Bot. 18, 391—397.
Romell, L.-G. 1922. Luftväxlingen i marken som ekologisk faktor. (Res. Die Bodenventilation als ökologischer Faktor). Medd. Stat. Skogsförsöksanst. 19, 125—359.
Samset, I. 1962. Vekten av hele grantraer (*Picea abies*). Tidsskr. Skogsbr. 70, 342—348.
Samuelsson, B. 1926. Studien über die Wirkungen des Windes in den kalten und gemässigsten Erdteilen. Bull. Inst. Geol. Upsala 20, 57—230.
Sanio, K. 1872. Über die Grösse der Holzzellen bei der gemeinen Kiefer (*Pinus silvestris*). Prigsh. Jahrb. wiss. Bot. 8, 401—420.
Shavnin, A. G. 1966. Povrezhdenie kornei i napennye gnili v el'nikah srednego Urala. Les. Z. 1966: 1, 169—171.
Sirén, G. 1950. Alikasvoskuusten biologiaa. (Summary: On the biology of undergrown spruce). Acta For Fenn. 58: 2, 1—90.
—»— 1955. The development of spruce forest on raw humus sites i northern Finland and its ecology. Acta For. Fenn. 62: 4, 1—408.

Sutton, R. F. 1969. Form and development of conifer root systems. Commonw. For. Bureau, Oxford, England, Technical Communication 7. 131 pp.

Veretennikov, A. V. 1968. Fiziologicheskie osnovy ustoichivosti drevesnykh rastennii k vremennomy izbytku vlagi v pochve. Moskva. 216 pp.

Werner, F. & Årmann, J. 1955. Stormfällningens dynamik — en studie. Sveriges Skogsv. Förb. Tidskr. 53, 311—330.

Wilson, B. F. 1970. Evidence for injury as a cause of tree root branching. Canad. J. Bot. 48, 1497—1498.

Yli-Vakkuri, P. 1953. Tutkimuksia puiden välisistä elimellisistä juuriyhteyksistä männiköissä. (Ref. Untersuchungen über organische Wurzelverbindungen zwischen Bäumen in Kiefernbeständen). Acta For. Fenn. 60: 3, 1—117.

7. SELOSTUS

HAVAINTOJA TUULEN AIHEUTTAMISTA LIIKKEISTÄ PUIDEN JUURISTOISSA

Tutkimuksen tarkoituksena on selvittää puiden juuristoissa tapahtuvia liikkeitä, jotka tuulen latvukseen kohdistuva taivuttava vaikutus saa aikaan.

Kun 24 puuta kallistettiin vinssillä, ja juurten liikkeitä seurattiin mittakelloilla, joilla voitiin mitata 0.01 mm:n liikkeet, oli rungon kallistuessa 1 asteen juuristossa todettavissa selviä liikkeitä, ainakin pystysuorassa suunnassa, joskin niiden suuruus riippui huomattavasti puulajista ja -yksilöstä sekä maalajista. Juurten liikuntoja tuulessa seurattiin mittakellojen, sähköisen potentiometrivastuksen sekä tätä tarkoitusta varten konstruoidun juuriliikepiirturin avulla. Tutkimus suoritettiin pääosiltaan Ruotsinkylän kokeilualueessa Helsingin lentoaseman meteorologisen aseman välittömässä läheisyydessä, josta saatiin tuulennopeusarvot.

Tuulen nopeuden ollessa noin 4—5 boforia, kuusen juuristoon aiheutuu varsinkin savimaalla ja turvealustalla tuulelle alttiilla paikoilla heiluva liike, joka tuulen kiihtyessä kasvaa niin, että sen pystysuora liike noin metrin päässä rungosta tuulen yläpuolella saattaa olla 4—5 cm. Männyllä ja kuusella hiekka- ja moreenimailla liike on paljon vähäisempää, kovassakin myrskyssä noin 0.1—0.5 mm:n suuruusluokkaa pystysuorassa suunnassa. Tämän lisäksi juuret liikkuvat rungon vedon johdosta myös pituussuunnassa, mikä männyllä on havaintojen mukaan usein suurempaa kuin pystysuora liike.

Havaintojen perusteella voidaan arvioida, että höllästi kiinni olevan kuusen lisäjuuret joutuvat taipumaan kymmeniäkin tuhansia kertoja vuodessa.

Tutkimusten perusteella erotettiin neljä tyyppiä juurten liikkeitä metsämaassa:

1) Juuristolevyn liikkeet, joita esiintyy varsinkin kuusella ja jossa pääjuureton juuristo liikkuu jopa useita metrejä laajana levynä.

2) Pääjuurellinen juuristo, etenkin männyllä, liikkuu siten, että pääjuuri taipuu samaan suuntaan kuin runko tuulessa. Pääjuuren liike on useimmiten vain 0.05 mm:n suuruusluokkaa.

3) Kuten edellinen, mutta pääjuuri liikkuu vastakkaiseen suuntaan rungon suhteen. Tällöin juurenniskasta lähtevät pintajuuret ilmeisesti pitävät juurenniskan niin tukevasti kiinni, että paksukin pääjuuri liikkuu juurenniska tukipisteenä.

4) Eräiden havaintojen mukaan saattaa koko juuristo-maapaakku liikkua yhtenäisenä kappaleena, jolloin tämän paakun ulkopuolella kasvaneet juuret joutuvat suurimman rasituksen alaisiksi. Todennäköisesti ryhmät 2—4 liittyvät hyvin läheisesti toisiinsa.

Useissa tapauksissa voitiin todeta puun kiinnittymisen maahan selvästi höltyneen. Tämä voitiin osoittaa siten, että puu katkaistiin n. 1 ½ metrin korkeudelta, jolloin tynkää voitiin usein heiluttaa hyvin pienellä voimalla.

Tutkimuksessa mitattiin 1 779:n yli 20 cm:n läpimittaisen männyn ja 1 406 samankokoisen kuusen runkojen poikkeama pystysuorasta. 32 % männyistä ja 14 %

kuusista oli kallistunut enemmän kuin yhden asteen, mikä osoittaa juuriston liikuntoja todennäköisesti tapahtuneen puiden kehityksen aikana.

Seuraavien rakennepiirteiden liikkuvien juuristojen juurissa otaksutaan johtuneen tuulen aiheuttamista liikkeistä:

1) Sivujuurista lähtevien ohuiden juurien tyven paksuuntunut kaarnakerros. 2) Juurten katkeamisesta johtuneet juurikimput. 3) Männyn syvällä olevat ilmeisesti hankautuneet juurien kärjet. 4) Juurten tyvien säikeiden kierteisyys ja vioittumat. 5) Trakeidien ja pihkatiehyeiden epämuodostuminen.

Kuusen juuriston liikunnot aiheuttavat varsinkin savipohjaisilla ja ohutturpeisilla mailla humus- ja turvekerrokseen jopa 5 cm:n korkuisia ja usean neliömetrin laajuisia onteloita, jotka tuulella jatkuvasti laajenevat ja supistuvat, aikaansaaden voimakkaita ilman ja veden virtailuja humuskerroksessa. Ontelon syntyminen ilmeisesti estää puiden juurten kasvua sen läpi pohjamaahan. Vain liikkeiden ollessa vähäisiä, ohuet juuret saattavat kasvaa ontelon poikki, mutta tällöin liikkeet aiheuttavat niiden muuttumisen voimakkaasti spiraalikierteisiksi.

Metsänhoidolliselta kannalta olisi edullista estää juuriston keinuvan liikkeen alkaminen lähinnä savi- ja turvemailla puiden saavutettua noin 3—5 metrin korkeuden. Parhaiten tämä käynee päinsä aikaisilla ja voimakkailla harvennuksilla.

Lisäksi tarkastellaan mahdollisuuksia käyttää kehitettyjä menetelmiä, lähinnä mittakelloja, arvioimaan yksittäisten puiden kaatumistodennäköisyyttä kovassa tuulessa.

INVESTIGATIONS ON THE ANNUAL CYCLE OF DEVELOPMENT OF FOREST TREES

Active period

RISTO SARVAS

TUTKIMUKSIA METSÄPUIDEN KEHITYKSEN VUOTUISESTA SYKLUKSESTA

Aktiivi periodi

TIIVISTELMÄ

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Preface

Investigation of the annual cycle of development of forest trees is part of an extensive study concerning different methods of the artificial regeneration of forests that is being conducted as team work by the Finnish Forest Research Institute. In treating seedlings, it should be noted that their natural growth rhythm must not be violated unreasonably. This is, however, what easily happens now that fertilized peat beds and plastic houses are used extensively for the growing of seedlings. This investigation has been carried out in cooperation with the Forest Genetics Department of the Forest Research Institute. In forest tree breeding, too, it has become very important to acquire an increasing knowledge of the natural growth rhythm and of how to describe it numerically. It is increasingly obvious that only such improved strains are of practical value whose annual cycle of development is similar to that of the local climate of the reforestation area. Only strains meeting this condition will survive in the long run.

Now that the first part of the investigation comprising the active period of the cycle has been completed, I wish to extend my sincere thanks to my numerous fellow workers who in their respective places of work in the field, laboratory, and office have contributed to the completion of this work.

The manuscript was read by Professor P a a v o J u u t i n e n, Dr. For. and Mr. V e i k k o K o s k i, Dr. Ph. and I am indebted to them for many suggestions for improvement.

The Finnish-language manuscript was translated into English by Mrs. M a r j a D e t h l e f s e n and the translation was checked by Mr. P e t e r J o n e s, B. A. for which I wish to thank them.

Helsinki, May 1972

Risto Sarvas

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Introduction

In the development of trees, particularly in temperate climates, a very distinct annual cycle can be seen: development starts at about the same physiological stage each spring and ends in another given physiological stage in the autumn. The purpose of this annual cycle is presumably to ensure that trees make full use of that portion of the year which is favourable for their various vital functions and that they safeguard themselves in good time against the hazards of the unfavourable season. It can also be said that the annual cycle of development reflects the genetic adaptation of trees to the annual climatic cycle of the habitat. As a matter of fact, only when based on this viewpoint can the study of the annual cycle rouse profound interest and, likewise, only then will it be possible to develop serviceable models of the cycle.

It should immediately be emphasized that not all the physiological activities in a tree are necessarily included in the sphere of the annual cycle. For instance, photosynthesis, respiration, and transpiration appear to be processes that occur, irrespective of the cycle, whenever the environmental factors afford the opportunity. In spring, however, the opening of the winter buds is a typical example of the phenomena comprising the annual cycle: even if environmental factors are very favourable, the buds do not open unless the cycle has reached a certain point.

The cycle is composed of several long sequences of physiological events which have become synchronized on the individual as well as on the population level. For instance, the development of a vegetative bud, the function of the cambium and the development of a flower bud are sequences of this kind. A common time-table is a prerequisite for the synchronization. When attempts are made to map out the cycle more accurately than before, this time-table merits special attention.

The cycle consists of two essentially different parts, i.e. the active period and the winter dormancy.

For the time being we will have to content ourselves with the statement that the active period begins when the winter dormancy ends, and that the active period ends when the following winter dormancy begins. Although

this definition is rather clumsy in form, it immediately brings out an important point: if only one of these developmental periods is investigated at a time, it does appear impossible to gain a clear notion of either of them and, therefore, attempts should be made to treat them as a whole. However, we will revert to the definition of winter dormancy and of the active period later on.

The foremost aim of the present study is to clarify the time-table of the active period. In other words, the study seeks, in the first place, to clarify the environmental factors that control the rate of speed of the physiological processes included in the active period and to determine how this control is accomplished.

The synchronization of the different physiological processes of an individual tree as well as of those of different trees appears to be possible only on condition that all the processes included in the sphere of the cycle react similarly to each of the environmental factors involved in this control[1]). In fact, the clarification of this principle is the fascinating basic problem of this study. It should also be emphasized that evidently the time-table must ultimately depend on a particular environmental factor or factors. The idea of an endogenous clock of some kind that is independent of the environmental factors is hardly realistic, although it is often presented. Obviously, all endogenous rhymes are ultimately produced by the joint influence of the genotype of a plant and the environment.

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[1]) This inference is particularly true also for vegetative and generative meristems. It does not seem plausible that a plant would simultaneously conform to two physiological clocks operating in accordance with different principles of which one would control the vegetative cycle, and the other the generative cycle. Let us take a widely known example: There is hardly anyone who has ever seen the male catkins in Betula verrucosa opening while the vegetative buds are still closed; neither is anyone likely to have ever witnessed pollen dissemination taking place only after the leaf is almost fully developed (the leaf is always half developed). A situation like this does not, of course, prove anything. However, the simplest model of reasoning that explains surprising facts of this kind is, no doubt, that the vegetative and generative cycles are controlled by physiological clocks operating in accordance with the same principle.

Definition of Concepts

Point Events and Segment Events

In investigating the progress of the active period it has proved appropriate to divide the physiological events into two categories: 1. point events, 2. segment events.

In this paper, a point event refers to an event in connection with which only two possibilities are conceivable: it has either taken place (sign +) or it has not taken place (sign —). Segment events (segment stages), on the other hand, are characterized by three stages: 1. the stage in question has not been reached, 2. the stage has been reached but it has not been passed through, and 3. the stage has been passed through.

For instance, the opening of pollen sacs is a typical point event. The sacs are either 1. closed or 2. open. There is no third alternative. A typical segment event is the receptive stage of the female flowers. There are three alternatives: 1. the female flowers have not reached the receptive stage, 2. the female flowers have reached the receptive stage but have not yet passed through it, and 3. the receptive stage has been passed through.

It is obvious that only in the case of a point event can the time be determined precisely. The beginning and end of a segment event are point events, and, therefore, a segment event is best investigated by determining the time of its beginning and end.

For instance, the height and radial growth of a tree are events that can be investigated as segment events whose beginning and end are precisely determinable as point events. But as regards the other physiological stages in their development, they offer no good point events for the time being.

In timing the point events it has proved appropriate to arrange the observations in such a way that they can be treated as cumulative frequencies. The following example will illustrate this procedure.

The task is to determine the time when the female inflorescences of *Pinus sylvestris* opened in Punkaharju study stand XLV in 1968.

In the terrain, investigations were carried out by observing 10 random female inflorescences in each of 15 trees chosen at random. In order to per-

Table 1. Data on Experimental Stands

Commune	Tree species	Sample stand no.	Geographical		Elevation above sea level m.	Area of stand ha	Stand				
			Latitude	Longitude			Year of measurement	Age yrs	Dominant height m.	Trees per ha	Volume cu.m.
Punkaharju	*Larix sibirica*	49	61°48.6·	29°18.3·	96	0.04	1969	42	19.2	425	196
»	*Larix sibirica*	D 8	61°48.6·	29°18.3·	96	0.13	1966	42	21.5	367	279
»	*Larix Gmelini*	D 9	61°48.6·	29°18.3·	96	0.13	1966	41	22.7	350	222
Bromarv	*Picea Abies*	I	60°02.4·	23°02.7·	27	6	1967	123	26.8	297	213
Punkaharju	*Picea Abies*	LII	61°48.8·	29°19.5·	92	1.5	1967	93	23.3	515	227
Bromarv	*Pinus sylvestris*	III	60°02.9·	23°02.5·	35	2	1967	60	21.7	360	158
Heinola	*Pinus sylvestris*	566	61°07.1·	26°00.9·	133	25	1967	124	23.1	112	87
Punkaharju	*Pinus sylvestris*	XLV	61°48.9·	29°18.3·	106	4	1967	116	22.2	328	207
»	*Pinus sylvestris*	LXI	61°47.8·	29°19.5·	86	1.0	1971	81	23.8	264	242
Helsinki	*Betula verrucosa*	167	60°12.3·	24°54.9·	32	0.15	1961	56	19.9	·	·
»	*Betula verrucosa*	LIV	61°49.0·	29°17.9·	90	1.5	1967	56	23.9	197	121
Kerimäki	*Betula verrucosa*	543	61°48.4·	29°24.5·	91	2.3	1967	·	24.9	332	174
Punkaharju	*Betula pubescens*	L	61°48.5·	29°19.5·	90	2.0	1987	67	20.1	320	117
»	*Betula pubescens*	XIV	61°48.8·	29°19.2·	85	2.0	1967	40	18.8	576	125
»	*Betula pubescens*	XIV					1971	44	19.3	576	132
»	*Betula pubescens*	LX	61°48.5·	29°20.0·	83	1.5	1967	41	16.7	624	105
»	*Alnus incana*	LXII	61°48.1·	29°18.3·	81	0.5	1967	41	15.4	545	92



Fig. 1. Aerial ladder mounted on a tractor and operated by the hydraulic pressure of the tractor. With the aid of this ladder it was possible to pick random samples of the vegetative and fertile buds of trees at a speed consistent with the method of investigation.

form this task fast enough it was necessary to use an aerial ladder mounted on a tractor and operated by the hydraulic pressure of the tractor (Fig. 1). In making observations, care was taken not to touch the inflorescences

themselves, for it had become evident that any disturbance may interfere with their subsequent development. Therefore, the inflorescences were brought into plain view by grasping the branches at a point sufficiently distant from the inflorescences concerned and moving them carefully as needed. For the observation, a lens giving twelvefold magnification was used.

In the investigation of the female inflorescences, attention was concentrated on the scales situated in the middle of the upper half of the inflorescences. If there were fissures, no matter how narrow, between these cone scales, the inflorescence was considered as being open (sign +); if there were no fissures, the inflorescence was not considered as being open (sign —). In principle, it is of the utmost importance that the difference between these two stages be established beyond doubt, because it is on this prerequisite the method stands or falls. In the above example, this condition was satisfactorily met.

Observations were made daily between June 8 and June 17. With the aid of the aerial ladder it was possible to make the observations so quickly that they were completed within an hour. This is, of course, important, because it simplified calculations in that 8.30 h. could be recorded as the time for each observation.

We now note that the proportion of plus observations, expressed as a percentage of the total number of observations (the total of plus and minus observations), indicates the cumulative frequency of the female inflorescences that were open at 8.30 h. on each observation day. The observations are thus ready to be handled on a frequency net (Fig. 2). Instead of calendar time, the heat sum, which had been calculated from the beginning of the year on the d.h. principle (threshold value 5°C, cf. Sarvas 1967, p. 214) was placed on the horizontal axis. On a frequency net it was possible to fit a straight line to the dot cluster without too much violation. From this line at the 50 % ordinate, it can now be seen that on an average the female inflorescences were opened (i.e. 50 % of them were open) when the heat sum reached 6 220 d.h. In 1968, according to the calculations of the cumulative heat sums carried out at crown level in study stand XLV, this occurred at 6.30 h. on June 13. It is of great additional value to have the standard deviation given by the difference between the abscissa values of 84 % and 50 %, which in this example is 100 d.h.

The method under discussion has a great advantage over several conventional methods of making phenological observations, in that all the observations made effectively contribute to the determination of the mean value which can consequently be calculated with remarkable accuracy. Another important advantage is that the standard deviation of the frequency distribution is obtained as a by-product. The whole frequency distribution will thus be clarified.

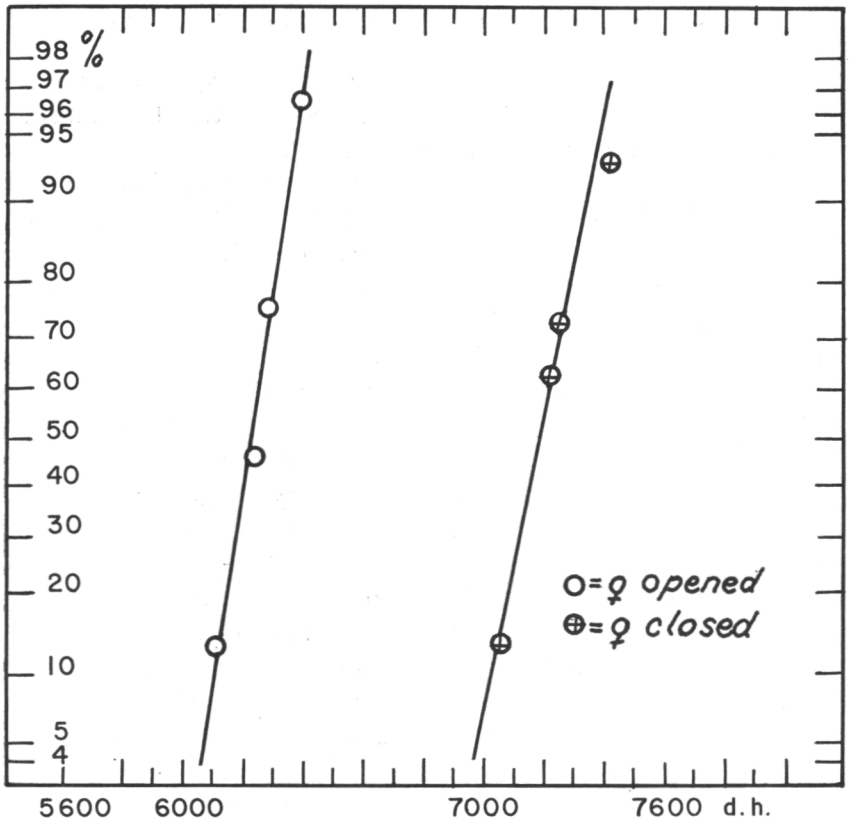

Fig. 2. The frequency sums of the opening and closing of the female inflorescences. *Pinus sylvestris*, Punkaharju 1968, sample stand XLV. The X of the opening of the female inflorescences = 6 620 d.h. (standard deviation s = 100 d.h.) The $\overline{x}$ of the closing of the female inflorescences = 7 180 d.h. (s = 110 d.h.). Thus receptivity lasted 560 d.h. (about 23 d.d.).

In this connection, attention should be paid to the wording of the example under consideration. The question was: at what time did the female inflorescences, on an average (50 %), open. At first, it might seem more sensible to inquire, for instance, at what time 90 or 95 % of the female inflorescences had opened (they never open 100 %). In principle, it does not, of course, make any difference what percentage is involved, since the whole frequency distribution is determined. However, it would appear most practical to choose 50 %, because the point of time is then independent of the standard deviation. For instance, in two Scotch pine stands where the female inflorescences, on an average (50 %), open at the same time, there may still be great differences between the opening times of 90 % or 95 % of the female inflorescences if the standard deviations differ in magnitude.

Cycle Interval, its Unit, and the Rate of Progress of the Active Period

The progress of the active period of a given genotype seems to depend almost exclusively on time and temperature (provided that the other environmental factors do not deviate essentially from those of the average environment to which the population is exposed in nature and that the reactions are homeostatic, cf. Sinnot et al. 1958, p. 29, cf. also Sarvas 1967, 1967b). Owing to this circumstance, the effect of temperature is given primary importance. Moreover, the progress of the active period appears to be an irreversible phenomenon.

The progress of the active period is the result of a large number of different biochemical reactions controlled by enzymes and hormones and occurring in a certain, accurately fixed sequence. Because of this, the successive stages of the active period are, to a great extent, incomparable with one another. Yet, it is reasonable to assume that all the physiological phenomena also have some common basic characteristics; it appears that at least the chain of events, which transmits the hereditary information contained in the genes to the enzymes regulating the physiological phenomena involved is, with regard to its basic construction, the same in all of them.

Thus it would seem that in referring to the progress of the active period and the rate of progress we actually mean the occurrence of these basic phenomena and the rate at which they occur. The method of investigation applied in this study does not lend itself to the observation of the actual basic phenomena but takes care of larger physiological units composed of them, and only a few of them, i.e. those that are easy to observe.

In endeavouring to become more closely acquainted with how time and temperature affect the progress of the active period, it seems useful to start from the assumption that at a constant temperature (under constant environmental conditions) the progress of the active period is proportional to time. Such an assumption is, of course, arbitrary, but it simplifies the initial examination of the matter.

From the above assumption it follows that the rate of progress of the active period, let us denote it by v, in a given genotype is merely a function of the temperature, T, or, in other words, $v = v(T)$. Thus the progress of the active period under constant thermal conditions, T, can be expressed by the following equation:

$$(1) \qquad P_1 \rightarrow P_2 = v(T)(t_2 - t_1)$$

in which P_1 and P_2 are the phases of the active period at times t_1 and t_2, and $P_1 \rightarrow P_2$ the cycle (period) interval between phases P_1 and P_2.

Let us now define the unit of cycle interval in the active period as follows: the unit of cycle interval of a given genotype is 1/5th of the cycle interval

that the active period of this genotype progresses in 1 hour at a constant temperature of 10°C. In the following, this unit is referred to as the period unit (p.u.). The period unit was determined in this way so that the magnitude of the unit should correspond as closely as possible to the magnitude of the period unit involved in the d.h. principle (degree hour principle, threshold value 5°C).

Defined in this way, the period unit is largely imaginary and its use involves certain significant restrictions. Owing to the fact that the different stages of the active period are not comparable with one another, the period unit cannot have a physical counterpart. It must be regarded only as a parameter that facilitates the numerical handling of certain characteristics of the active period.

From the definition of the period unit and the rate of progress of the active period it follows that each individual tree, each genotype, acquires its own unit. At first, it may seem that we are about to drift into an almost fruitless situation: the number of period units formed equals that of the genotypes, i.e. an almost infinite number. In spite of this difficulty, it would seem possible to make progress along these lines and obtain results of a general nature, as we shall seek to demonstrate in the following. To begin with, we shall confine ourselves to the examination of a single genotype.

Let us now revert to page 12 and scrutinize equation (1). When the temperature fluctuates, the amount of progress of the active period is shown by the integral

$$P_1 \rightarrow P_2 = \int_{t_1}^{t_2} v\,(T(t))\,dt \tag{2}$$

in which T (t) is the temperature at time t and v (T) the rate of progress of the active period at temperature T.

Equation (2) can, for the sake of practical calculations, be written in the form

$$P_1 \rightarrow P_2 = \sum_{i=1}^{n} v\,(T_i)\,t_i \tag{3}$$

in which i is the i'th temperature measurement when the time lapse from P_1 to P_2 is divided into n equal parts.

In examining the active period, it is often necessary to know a cycle interval that has for its initial phase (P_1) the cessation of winter dormancy, that is to say, the zero phase of the active period. Equation (3) then takes the form

$$P = \sum_{i=1}^{n} v(T_i)\, t_i \tag{4}$$

where i is the i'th measurement of temperature from the beginning of the active period.

We now observe that for reckoning the cycle interval corresponding to a given time interval, the only unknown is v. It is evident that v can be determined experimentally.

Experimental Determination of the Rate of Progress of the Active Period

Experimental Method

The extent to which the rate of progress of the active period is dependent on temperature can be determined experimentally. It is only necessary to choose suitable material in which typical phases of the active period can be readily and sharply distinguished, and arrange for development to occur under different constant temperatures.

The irreversible nature of the active period does, of course, mean that the same material cannot be used for experiments more than once, i.e. at more than one constant temperature, but by taking representative samples from a sufficiently large group (population) one can obtain numerous matched sets.

For instance, the microspore mother cells of some tree species have proved to be appropriate objects for study. During meiosis, the progress of the active period of microspore mother cells includes numerous good point events which occur at intervals that are suitable for experimental purposes. The different stages of meiosis, in the form in which they are conventionally described and defined, are actually not point events but segment events. But the beginning and end of each of them are point events. It is improbable that the beginning and end of the various stages have ever been precisely defined but rather the description of each stage has generally been confined to a point characteristic of that stage. With this in mind, in this study, it was the beginning of each stage that was chosen as the point event to be investigated. In defining the beginning of each phase the purpose of this study was primarily considered. It is possible that our definition does not correspond exactly with prevailing practice.

Experiments to be made on the development of the microspore mother cells can, for instance, be so arranged that the time lapse between metaphase I (MI) and metaphase II (MII) is measured at different constant temperatures.

From equation (1) on page 12 we then obtain

$$v\,(T) = (MI \rightarrow MII) : (t_2 — t_1) \tag{5}$$

The time interval between MI and MII at a constant temperature of 10.0°C is denoted by h_{10} and the times measured at other constant temperatures are correspondingly denoted by h_T.

We now obtain:

$$v\,(T) = (MI \rightarrow MII) : h_T$$

$$v\,(10°) = (MI \rightarrow MII) : h_{10}$$

and from this we further obtain

$$\frac{v\,(T)}{v\,(10°)} = \frac{h_{10}}{h_T}$$

and since, according to the definition,

$$v\,(10°) = 5 \text{ p.u./h.}$$

we obtain

$$v\,(T) = 5\frac{h_{10}}{h_T} \text{ p.u./h.} \tag{6}$$

In the spring of 1968, experiments were made with the microspore mother cells of *Populus tremula* and in the spring of 1969, with the opening of the male catkins in *Betula verrucosa* and *B. pubescens*. Further, when the study was at the manuscript stage, experiments were made with the microspore mother cells of *Larix sibirica* and *Larix Gmelini*. Thus, experiments have been carried out with five different tree species and these experiments are described below.

Experiments with Populus tremula

In respect of controlled experiments with microspore mother cells, *Populus tremula* is suitable in that it affords certain methodical advantages over several other species. By collecting the twigs early in the spring before the cessation of winter dormancy it is easy to catch the meiotic stage. The fixing of the male buds is simple, because the anthers are easy to uncover and dissect from the bud. Another notable advantage is that the twigs are leafless at the time of meiosis and therefore easy to handle in incubators.

All the twigs used in the experiments were taken on March 29, 1968 from a single tree with abundant male buds.

The twigs were stored in an ice cellar where the temperature varied from 0.5°C to 1.0°C. For each experiment, the necessary number of twigs were taken out at random. However, the study material was not methodically homogenized at first, that is to say, care was not taken that each subgroup of twigs was truly representative of all the twigs stored in the cellar. This proved to be a shortcoming and the procedure was rectified later. The twigs were cut about 30 cm. long, tied up in bundles and placed in incubators (Figs. 3 and 4).

All the constant temperatures involved except those at about zero were produced with incubators having a cubic volume of about 286 liters and provided with ventilation. The heat was regulated with a Danfoss thermostat. The temperature fluctuated at around 0.5°C. The temperature was checked 3 times a day with an Ellab thermocouple. Readings were taken at half-minute intervals, starting when the thermostat switched on the cooling and ending when the thermostat again switched on the cooling a second time (after having switched it off in between). Thus, at each time of checking, the readings obtained covered a complete cycle of temperature fluctuations in the incubator. The ultimate experimental temperature was calculated as the mean value of all the check readings obtained during the experimental period.

Vapor pressure and relative humidity were determined with the aid of an Ellab psychrometer from which the temperatures of a wet-bulb and

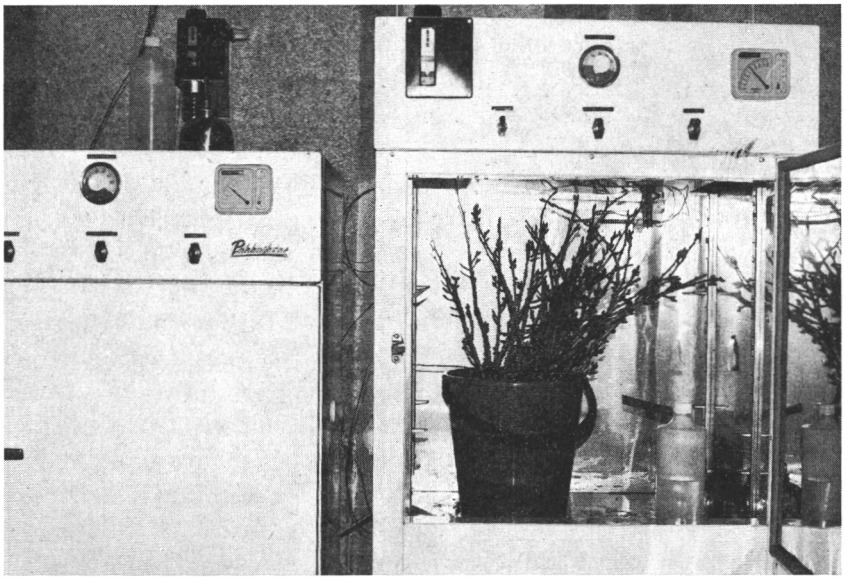

Fig. 3. *Populus tremula* experiment in progress in an incubator. The thermocouple is among the twigs.

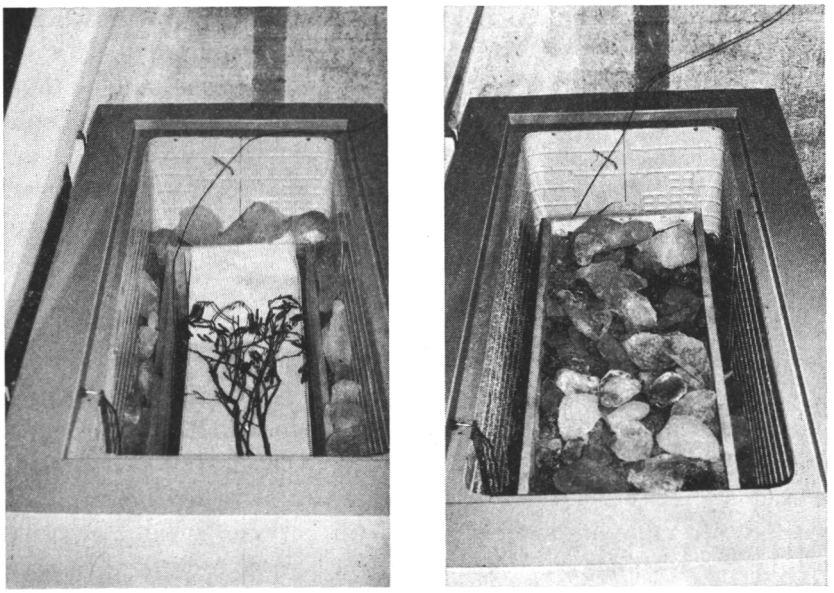

Fig. 4. Experiment with *Larix sibirica* at 0°C. The temperature of the refrigerator is set atabout + 2.0°. There are chunks of ice at the bottom of the chest and on top of them, surrounded by ice, is a wooden box containing the experimental twigs. Chunks of ice also cover the lid of the box. The thermocouple is among the twigs. Ice is added when necessary. Among the twigs, the temperature fluctuates between 0.0 and 0.1°C. Left the box is open, right covered with the lid and with ice.

dry-bulb thermometer are read by means of a thermocouple. Humidity was regulated by wetting a piece of blotting paper on the bottom of the incubator. Relative humidity fluctuated between 0.60 and 0.80.

No lighting was installed in the incubators, so the experiments took place in almost complete darkness.

The twigs were tied up in bundles containing about 30 male buds per bundle. Five to ten bundles were placed in water containers in each incubalor. During the fixing, the incubator doors could be kept closed except when a bundle was removed.

Before the buds were placed in the fixative, the bracts were removed so as to enable the solution to reach the microspore mother cells quickly. Fixing was done in acetic alcohol in which the ratio between the acetic acid and absolute alcohol was 45 : 55. The fixing solution was always mixed just before each fixing. Care was taken to keep the temperature of the solution at about 10°C. The ratio between the cubic volume of the fixing solution and that of the buds was (10—50) : 1. Fixing required at least 48 hours.

Samples were fixed at intervals that varied between 0.5—6.0 hrs., depending on the temperature. The aim was that each subexperiment (temperature) should include about 5—10 separate fixations.

The preparations were made with the squash method and stained in acetic-orcein, whereupon they were examined. The microspore mother cells in each preparation all originated from a single male bud. From each preparation, 50 microspore mother cells were studied. Each fixing comprised 20 buds. Thus, for each fixing about 1 000 mother cells were examined.

The microscope readings obtained were recorded on forms duplicated for this purpose. Also, the cumulative frequency was calculated on this form. Although the experiments were primarily conducted to determine the lapse of time between MI and MII, the meiotic phase of each mother cell was noted on the form.

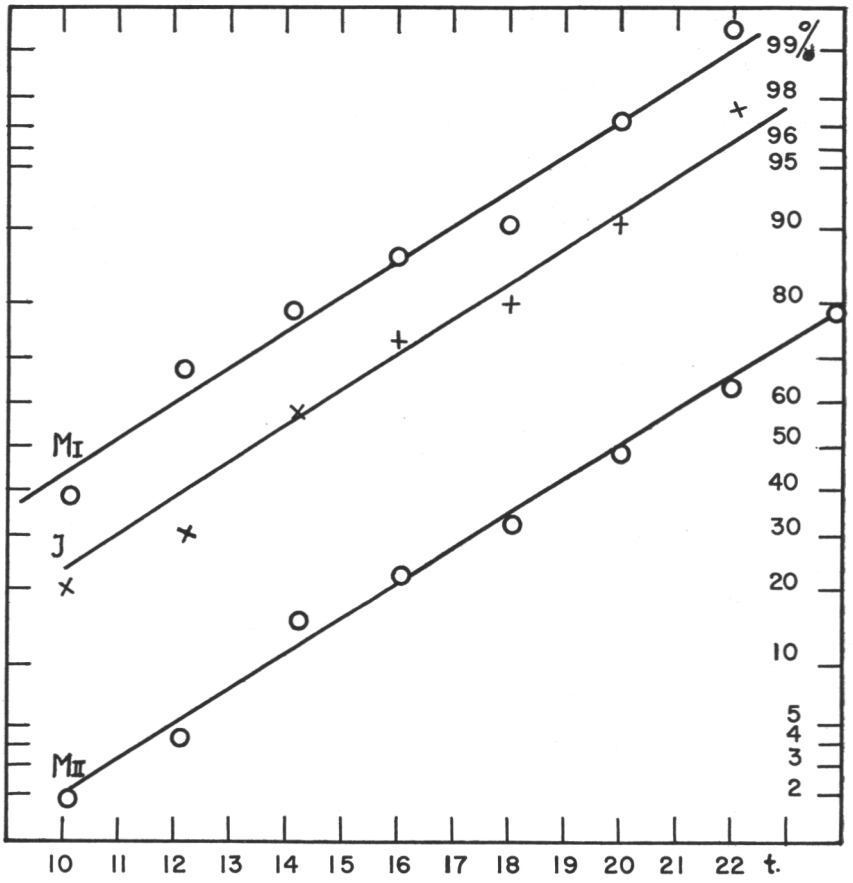

Fig. 5. *Populus tremula*, Kerimäki, Silvola. Meiosis in microspore mother cells at a constant temperature of 8.2°C. The horizontal axis shows the time lapse reckoned from the beginning of the experiment. It is expressed in hours. The vertical axis shows the frequency sums of microspore mother cells that reached metaphase I (MI), interphase (I) and metaphase II (MII). The time lapse between MI and MII is 9.3 hrs.

On a frequency net, straight lines were fitted to the cumulative values. This is demonstrated by Fig. 5 showing the results obtained from a subexperiment made at a constant temperature of 8.2°C.

The first point event on which observations were made was diplotene, and this was followed by diakinesis, metaphase I, anaphase I, telophase I, interphase, prophase II, metaphase II, and so forth. Since matched material was used for the investigation of all the phases, the standard deviation of the frequency distribution of each phase is approximately of the same magnitude, and from this it follows that the lines must be almost parallel. This leads to the remarkable advantage that when straight lines are fitted simultaneously to the dot graphs representing each meiotic phase, the lines support one another and thus increase reliability. All the material investigated microscopically in the course of one subexperiment (at one constant temperature), a total of about 9 000 mother cells, was thus efficiently utilized in the determination of the time lapse between MI and MII.

With a few exceptions, the scatter of the dots around the fitted line is rather small. This is due to the large amount of material investigated; it should be remembered that each dot represents about 200 mother cells. Actually, the innate variation in the material is very great. For instance, in the material shown in Fig. 5, the standard deviation of the frequency distributions is about 9 h. Since the time lapse between MI and MII is 12.9 h., the standard deviation from this time is about 70 %.

It is the great standard deviation of the frequency distribution of the different phases of meiosis that has proved to be the most significant of the factors restricting the present experiments. It is in itself a problem that remains to be solved. There is a great deal of accumulated evidence to suggest that in the autumn the active period of all pollen mother cells ends at the same physiological stage (diplotene) in which they survive the winter. It would thus be reasonable to conclude that in the spring, when dormancy stage ends, the active period of each mother cell begins from the same developmental point and that the variation between the developmental stages of the different mother cells is slight, at least at the beginning.

Even within a single bud, the developmental stages of different mother cells differ to a surprising extent (cf. E k b e r g et al. 1967, p. 11) but the differences are very much greater between different buds. It seems obvious that at the present phase of the study our knowledge is inadequate for an understanding of the magnitude of the variation. Above all, much more information on dormancy is required than is available at the present time.

Fig. 5, p. 19 demonstrates how the time lapse between MI and MII at a constant temperature of 8.2°C has been determined. From the horizontal line at 50 % it can be seen that on an average (50 %) the mother cells passed MI within 10.9 hours and MII within 20.2 hours counted from the

Table 2. The time lapse between metaphase I (MI) and metaphase II (MII) of the meiosis in the microspore mother cells of *Populus tremula* at some constant temperatures. Punkaharju, Spring 1968

Experiment began	Temperature	Fixing		Time MI → MII	MI distribution	
date	+°C	Interval hrs.	Number of times	hrs.	s	c
19. 4.	0.0	40—65	4	62.0	38.0	0.53
16. 4.	0.3	22—24	3	55.0	31.0	0.57
18. 4.	1.2	15—50	4	44.0	24.0	0.54
17. 4.	4.2	4—12	6	78.5	9.8	0.53
21. 4.	6.1	3—4	5	12.0	6.8	0.56
22. 4.	8.2	2	8	9.3	4.8	0.52
19. 4.	10.6	1—2	5	5.0	2.9	0.66

beginning of the experiment. The time lapse between MI and MII is 20.2—10.9 = 9.3 hrs.

The time lapse between MI and MII at 7 different temperatures was determined by this method. The highest temperature at which the meiosis of *Populus tremula* occurred undisturbed was about 11°C. Experiments could not be conducted with this material at temperatures above 11°C.

The results of the experiments have been compiled in Table 2. In the experiments at 0.0°C, male twigs were placed among melting ice in an cellar where the air temperature was about 0.3°C. The temperature was checked twice a day. At each check, the temperature was exactly 0.0°C. It was surprising to find that the meiosis of *Populus tremula* occurred regularly at a temperature as low as this, even though it took a very long time. Presumably, meiosis would have occurred even at a temperature somewhat below zero, but would have been even slower. At zero temperature, the time lapse between MI and MII was 62 hrs. or 2 days and 14 hrs. At 10.6°C, the corresponding time lapse was only 4.4 hrs., or about one-fourteenth part of the time measured at zero temperature. This difference demonstrates how closely the rate of progress of the active period depends on temperature. This result is in conformity with the results arrived at by Chira (1964) in his studies on the microsporogenesis of *Taxus baccata;* Chira also established meiotic activity at temperatures near 0°C.

It should, maybe, be pointed out that these findings clearly deviate from the data published by Barner and Christiansen (1960, p. 3) and Christiansen (1960, p. 72) concerning meiosis in *Larix decidua:* »It was further found that PMCs at the meiotic metaphase I (abbrev.: M_1) in male buds of twigs of larch stopped divisions when placed in a refrigerator at a temperature of 0° — +3°C . . . .» In these publications, there is no indication of the approximate number of buds and mother cells on which the data are based. It is possible that the number of buds was not so large

(about 20—30 buds per fixing) as the great variation between buds would require. Another thing to be considered is the fact that Barner and Christiansen investigated *Larix decidua*, whereas the present data are for *Populus tremula*. However, in connection with the present study, the meiosis of several *Larix* species (*L. Gmelini*, *L. sibirica*, *L. decidua*) was also investigated at a temperature of 0°C and its progress was found to be similar to that of the meiosis of *Populus tremula*.

An experiment made at zero is also important in that it proves convincingly that the beginning of the progress of the active period is not tied to temperatures above a relatively high threshold value, such as 4°, 5°, or 6°C, but begins at temperatures below zero. True, the rate of progress of the active period is very slow at temperatures below zero.

The standard deviations of these distributions are shown in Table 2. The more rapid the progress of meiosis, the smaller, of course, is the standard deviation of the frequency distribution. Therefore, interest is centred, in the first place, on the variation coefficient. A parameter closely corresponding to the variation coefficient is reckoned by dividing the standard deviation by the time lapse between MI and MII. From the last column in Table 2 it can be seen that in all the experimental series except the last (bottom line) the parameter thus obtained is almost the same, varying between 0.52 and 0.57. This is, of course, because the same material was used in all the experiments and the variation within the material was practically the same in the different series. The fact that the innate variation was really almost the same lends support to the view that, on the whole, the experiments and the interpretations placed on them were satisfactory. It may be only a coincidence that in the experiment conducted at 10.6°C, this parameter is clearly higher than in the others, but it may also be an indication that at a temperature of 10.6°C meiosis in *Populus tremula* is no longer quite regular: the temperature in question may approach the tolerance limit beyond which normal genotypic control obviously starts to fail; in other words, the responses are no longer homeostatic. The consideration mentioned last is fundamental in experiments such as the present ones. In this connection reference is made to Chira's (1964) investigations on the meiosis of *Taxus baccata;* Chira found (German summary, p. 244) that a 12-hour exposure to a temperature of 30°C was fatal for the microspore mother cells. Thus, when an individual tree is said to have inherited the inclination to react to a given environment in a way consistent with the physiological homeostasis of the individual tree concerned, it must be remembered that this rule generally holds true only in environments that do not deviate essentially from the evolutional environment of the population to which the individual belongs. In southern Finland, at the time of meiosis of *Populus tremula*, the temperature seldom rises above 10°C for even a few hours, much

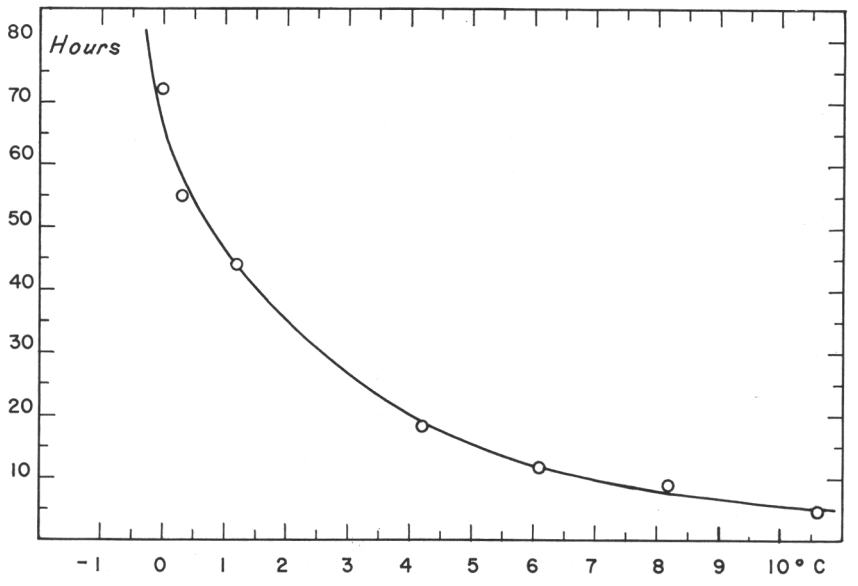

Fig. 6. Regression of the time lapse between MI and MII on temperature. Meiosis in the pollen mother cells of *Populus tremula*, Punkaharju.

less for a period of, say, 8 hours. If an experiment is so arranged that the temperature is considerably above 10°C, it should be noted that this may exceed the limit of tolerance and the reactions may no longer be homeostatic.

Experiments were also made at temperatures of 15° and 21°C, but the meioses were greatly disturbed; hence, the results are not reported here. Apparently, at temperatures above 11°C the rate of progress of the active period should be determined by investigating point events which in nature occur on an average at temperatures higher than those at which the meiosis of *Populus tremula* takes place.

The data in Table 2 have been plotted in Fig. 6 as a dot graph and a free-hand curve has been fitted to it. All the values necessary for determining the rate of progress of the active period at temperatures below 11°C can be obtained from this curve by interpolation. For calculation of results, one series of tests should have been made at a constant temperature of exactly 10°C (cf. p. 16) but in the incubators that were available it was difficult to regulate the temperature at the desired level even with an accuracy of only 0.1 %. However, since interpolation can be resorted to, this was not absolutely necessary. For instance, in Fig. 6, the time lapse between MI and MII at a constant temperature of 10°C is found to be 6.0 hours by interpolation.

Experiments with Betula verrucosa and Betula pubescens

As mentioned before, it became evident in the spring of 1969, when experiments were conducted with the meiosis of *Populus tremula*, that if the temperature was raised above 11°C the rate of meiotic disturbances increased. It was, therefore, decided that in subsequent experiments the point event chosen should be one that would often occur in nature at relatively high temperatures. The opening of the male catkins in *Betula verrucosa* and *Betula pubescens* was chosen as this point event.

In later experiments, we tried to profit from the experience gained from the difficulties encountered in 1968. As has already become evident, one of the greatest difficulties in determinig the rate of progress of the active period is the great variation between buds. In order to overcome this difficulty, it is necessary to use large quantities of buds. This, again, presupposes that the method used is comparatively simple and fast. Otherwise the whole project may come to nothing as a result of the huge amount of work. The following method, which is based on the opening of male catkins, appeared promising in this respect.

From a single *Betula verrucosa* tree with abundant male buds (curly birch plantation No. 362, Punkaharju, sample plot LXIII) about one thousand terminal twigs varying in length between 30—50 cm. were collected. They were taken into a cellar equipped with refrigeration, where the temperature was about 8°C. Here, on a table, the twigs were first laid out in a row. Representative samples of the whole collection were formed by picking from the row every tenth twig till the number of twigs in each bundle had reached 25. Each of these bundles contained about 200 male catkins.

The bundles were placed simultaneously in incubators at 9 different constant temperatures (8°—28°C). At intervals of 4 hours, each bundle was checked and the catkins that had opened were removed. At each inspection, the number of catkins removed and the exact time of observation (but nothing else) were recorded. After each observation, the twigs were sprayed with water. At the same time, care was taken that the relative humidity of the air surrounding the twigs continued to be high (60—80 %).

A male catkin that had just opened was used as the criterion to distinguish between closed and opened male catkins. This catkin, preserved in 60 % alcohol in a small fixing jar, was always kept at hand during the inspections.

The opening of the male catkins is a good point event because it is easy to distinguish beyond doubt. Also, it has the advantage over such an event as the dehiscence of the pollen sacs of the anthers, that it occurs almost regardless of fluctuations in the humidity, provided the humidity is high enough (over 60 %) to prevent the catkins from drying, a danger that always attends experiments of this kind.

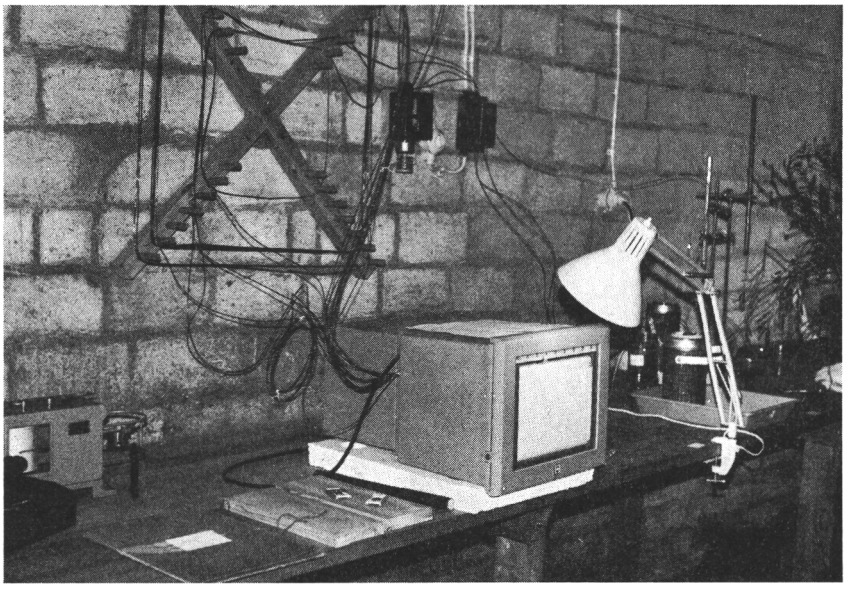

Fig. 7. The »constant temperatures» employed in the experiments were controlled with the aid of thermocouples attached to a multipoint recorder. The control temperature, 0.0°C, was maintained in the thermos flask seen behind the recorder by taking care that the flask constantly contained about 2/3 ice and 1/3 water. The recorder was installed in a cellar were a roughly constant temperature was maintained.

The basic idea behind these experiments was to determine the time that elapsed, at different constant temperatures, from the beginning of the experiment until 50 % of the male catkins had opened. The first point event was the physiological stage which 50 % of the male catkins had just passed when the experiment was begun (we do not know what this stage is but this is immaterial) and the second point event was the stage mentioned above at which 50 % of the male catkins had opened. Thus, the object of measurement was the time that elapsed between these two point events, at different constant temperatures.

In these experiments, the temperatures of most of the incubators were measured by means of thermocouples attached to a multipoint recorder.

Another improvement in these experiments was the use of decimal time in which hours and minutes are expressed as decimals of a day (24 hours) and the days are given successive numbers, beginning with the 1st day of the year. Application of decimal time greatly facilitated the calculations, which when based on conventional time units are time-consuming.

The experiments progressed successfully in every respect. The observational results of each separate experiment were treated as cumulative frequencies on a frequency net. The results have been compiled in Table 3.

Table 3. Data on the time lapses between the beginning of the experiment and the opening of the male birch catkins at different constant temperatures. *Betula verrucosa* and *Betula pubescens*

Tree species	Constant temperatures, °C						
	7.9	10.3	11.9	15.7	18.2	24.1	29.1
	Opening of male catkins, time lapse in hours						
Betula verrucosa	172.8	111.6	96.0	54.2	43.7	29.3	25.2

Tree species	Constant temperatures, °C						
	7.7	9.2	11.7	15.9	18.2	23.8	25.3	29.3
	Opening of male catkins, time lapse in hours							
B. pubescens, series 1.	135.1	96.0	57.6	34.1	26.4	18.2	16.3	15.1

Tree species	°C			
	10.0	18.2	23.8	35.1
	Hours			
Betula pubescens, series 2.	50.9	17.0	12.0	9.40

The method described above in connection with *Betula verrucosa* was also applied in connection with the experiments made with *B. pubescens*. These experiments were conducted in two parts. The first covered 9 constant temperatures and the second 4. These experiments, too, progressed undisturbed in every respect. The results are seen in Table 3.

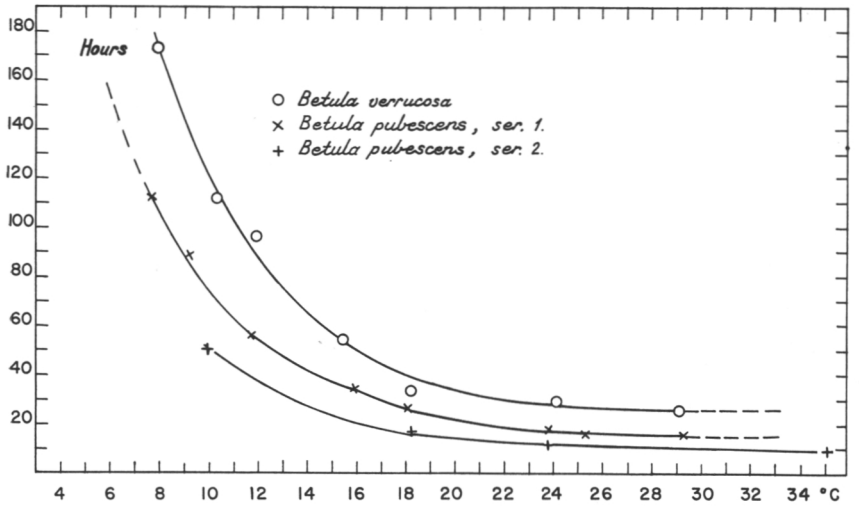

Fig. 8. The time lapses between the beginning of the experiment and the opening of male birch catkins at different constant temperatures. *Betula verrucosa* and two experimental series of experiments with *Betula pubescens*.

The data were plotted on coordinate paper and free-hand curves were fitted to the dot graphs (Fig. 8). The diagram shows the time required for the active period to progress the cycle interval investigated in each of the experimental series.

Experiments with Larix sibirica and L. Gmelini

At the time when the present study was at the manuscript stage, experiments on the winter dormancy were under way and they produced, as by-products, data on the active period.

From the point of view of the present study, these data are particularly significant in that they increase the number of tree species on which the final results are based from 3 to 5, and the number of genera from 2 to 3. Furthermore, through these tests the study came to cover the gymnosperms in addition to the angiosperms investigated earlier.

As the study progressed, an effort was made to improve the investigatory methods in every respect. As pointed out in the foregoing, the greatest difficulty from the methodical point of view results from the great variation between the buds of an individual tree (topophysis). It has become increasingly obvious that the only means of overcoming this difficulty is to make sure that every sample fixed is representative of the whole material collected.

Tree species: Larix sibirica Commune: Punkaharju Sample stand 49 Tree 14

Picking date: 27.11.1969 Preparatory treatment: Outdoors

Treatment began: 1.12.69 13.00 o'clock (335.542) Temperature: 7°C

Preparation No.	Fixing time 0.000	Degenerating mother cells	Meiotic phases														Total
			Pro-pachytene	Pachytene	Diplotene	Diakinesis	Metaphase I	Anaphase I	Telophase I	Interphase	Prophase	Metaphase II	Anaphase II	Telophase II	Tetrads	Pollen	
			Number of Mother cells														
1	341.549	-			18	-	1	-	1	22	3	7	1	11	36	-	100
2	"	-			18	1	5	-	2	18	6	6	2	9	32	1	100
3	"	-			33	2	4	-	-	13	1	3	-	-	44	-	100
4	"	-			40	-	13	3	1	11	1	2	-	1	28	-	100
5	"	-			53	-	7	-	1	10	1	4	-	2	24	-	100
6	"	-			37	-	5	1	2	13	-	4	2	2	33	1	100
Total			-	-	199	3	35	4	7	87	12	24	5	25	197	2	600
Cumul. sum					600	401	398	363	359	352	265	253	229	224	199	2	
Cumul. %					100.0	66.8	66.3	60.5	59.8	58.7	44.2	42.2	38.2	37.3	33.2	0.33	

Fig. 9. Form used and filled out in connection with the investigation of meiotic preparations.

This means that each sample must be random and sufficiently large. To meet either of these conditions is more difficult than may at first appear. The first condition has been met by randomizing the buds to be fixed. As to the second requirement, the minimum number of buds to be included in a fixation has been increased to 20—30. However, examination of a large number of buds involves much microscopical work — so much, in fact, that the progress of the study is jeopardized. On account of this, the following method has been employed. About 20 anthers are dissected from each bud and placed in orcein on a watch glass. They are squashed all at once, from which it follows that the mother cells originating from the various buds become thoroughly mixed up. A drop of this liquid is placed with a pipette on each of 4—6 slides, and the preparations are made. From each preparation, 100 mother cells are examined. The method of examination is further illustrated by the form used in this connection. It is shown in Fig. 9.

Table 4. Data on the time lapse between metaphase I and metaphase II of the meiosis in microspore mother cells of *Larix sibirica* and *Larix Gmelini*

Temperature, °C									
0.3	1.6	2.1	3.1	4.0	5.1	6.1	7.0	8.0	9.6
Time expressed in days									
Larix sibirica, plantation No. 49, Punkaharju									
8.0	5.8	4.5	3.9	3.0	2.5	2.2	1.6	1.0	1.0
Larix Gmelini, plantation No. 9, Punkaharju									
—	4.5	4.6	3.8	2.8	—	2.0	1.4	1.5	0.9

The observations made have been treated in the same way as those for *Populus tremula* (p. 16). The times measured between MI and MII at different constant temperature conditions are shown in Table 4. A graph (Fig. 10) reveals that there is no appreciable difference between *Larix sibirica* and *L. Gmelini*, whereas the difference between *Populus tremula* (Fig. 6, p. 23) and the *Larix* species is surprisingly large. For example, in respect of *Populus tremula*, the time measured between MI and MII at a constant temperature of 2°C is 35 hrs. (1.46 days), but the corresponding interval in the active period of the *Larix* species is 4.5 days. It is tempting to speculate that this may be due to the different size of the chromosomes. The long, thick chromosomes of *Larix* species are, perhaps, much slower in their movements and clumsier in getting organized than the very small-sized chromosomes of the *Populus* species. — The data will be examined in greater detail in subsequent pages.

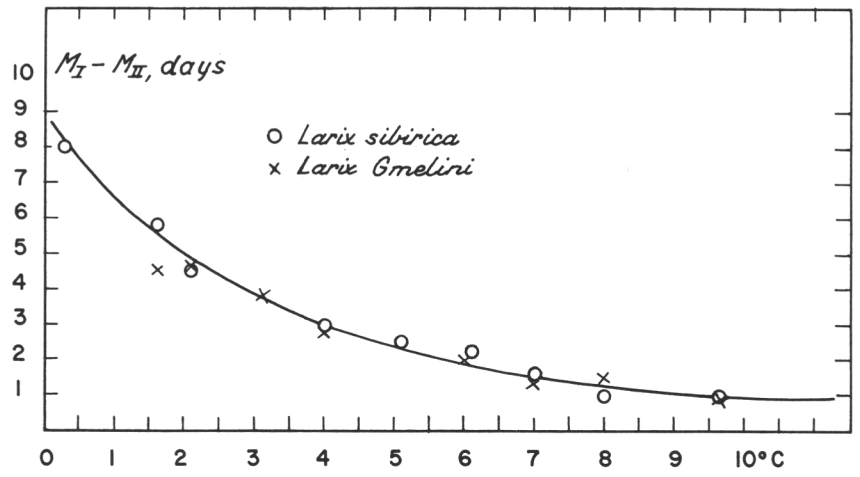

Fig. 10. Meiosis in the microspore mother cells. The lapse of time was measured between metaphase I and metaphase II in different constant temperature conditions.

Synthesis of Experimental Results

In defining the rate of progress of the active period and the cycle interval it was established (p. 13) that individual trees, including even those of the same species, could not be given a common unit for the cycle interval of the active period but rather each individual tree, i.e. each genotype was assigned its own unit. This is a significant restriction that interferes with the combining of the experimental data.

For examination of the data, the rate of progress of the active period in each experiment was first calculated on the basis of equation (6), p. 16. This equation indicates that the rate of progress of the active period under any constant temperature conditions (T) is obtained by dividing the time (h_{10}) required for the active period to progress a given interval at a constant temperature of 10°C by the time (h_T) required for the active period to progress the same interval at a constant temperature of T and by multiplying the quotient by 5. Where there is no experimental value for h_{10}, this is determined by interpolation between two close h_T values.

The results of the calculations based on the experiments made with *Populus tremula* and *Betula* species can be seen in Table 5. In Fig. 11 the results are presented graphically as the regression of the rate of progress of the active period on temperature. A free-hand curve has been fitted to the dot graph.

The fact that a curve can be fitted to the dot graph without obvious violation of the graph is evidently the most significant experimental result

Table 5. Data on the rate of progress, v (T), of the active period at different constant temperatures (T)

Experimental object	Experim. temperature T	Time expressed in hours		v (T) p.u./h. = $5 \frac{h_{10}}{h_T}$
		h_{10}	h_T	
Populus tremula, meiosis in microspore mother cells, MI → MII	0.0	6.5	62.0	0.527
	0.3	6.5	55.0	0.590
	1.2	6.5	44.0	0.736
	4.2	6.5	18.5	1.75
	6.1	6.5	12.0	2.77
	8.2	6.5	9.3	3.49
	10.6	6.5	5.0	6.50
Betula verrucosa, opening of the male catkins	7.9	122.6	172.8	3.54
	10.3	122.6	111.6	5.49
	11.9	122.6	96.0	6.40
	15.7	122.6	54.2	11.40
	18.2	122.6	43.7	14.10
	24.1	122.6	29.3	20.9
	29.1	122.6	25.2	25.5
Betula pubescens, opening of the male catkins, series 1	7.7	73.7	135.1	2.74
	9.2	73.7	89.0	4.15
	11.7	73.7	57.6	6.38
	15.9	73.7	34.1	10.8
	18.2	73.7	26.4	13.8
	23.8	73.7	18.2	20.0
	25.3	73.7	16.3	22.4
	29.3	73.7	15.1	24.3
Betula pubescens, opening of the male catkins, series 2	18.2	50.9	17.0	15.0
	23.8	50.9	12.0	21.2
	35.1	50.9	9.40	27.0

obtained in the course of the present study. It is also a surprising result when one considers that several tree species and individual trees, whose unit rates presumably vary, are involved and, furthermore, that cycle intervals pertaining to the various parts of the active period have been investigated. The result will be examined in greater detail in subsequent pages.

Also, the general form of the curve immediately draws attention: the curve resembles the delineator of the cumulative function of the normal frequency distribution. The coordinates of the inflexion point are $x = 18.2°C$ and $y = 14.0$ p.u./h. The limit value approached by y while x grows is thus $2 \times 14.0 = 28.0$ p.u./h. Fig. 12 shows on a frequency net this cumulative function. Transformation was accomplished by dividing the rates of progress calculated on the basis of experimental results by 0.28 (Table 5, the last vertical column). A free-hand straight line was then fitted to the dot graph.

From Fig. 12 it can indeed be seen that the regression of the rate of progress of the active period on temperature can be surprisingly accurately inter-

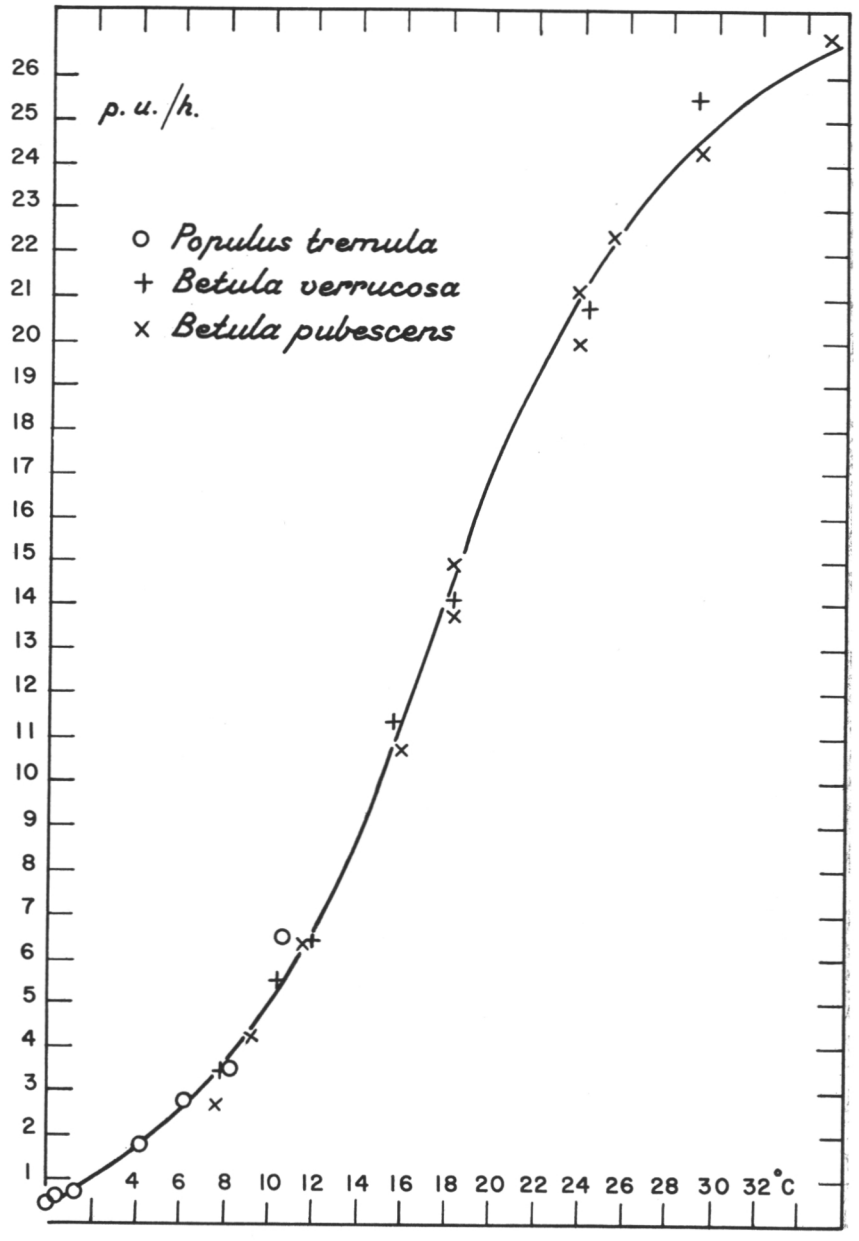

Fig. 11. Regression of the rate of progress of the active period on temperature. Investigatory objects: *Populus tremula*, meiosis in the microspore mother cells, cycle interval MI—MII. *Betula verrucosa* and *B. pubescens*, lapse of time between the beginning of the experiment and the opening of the male catkins.

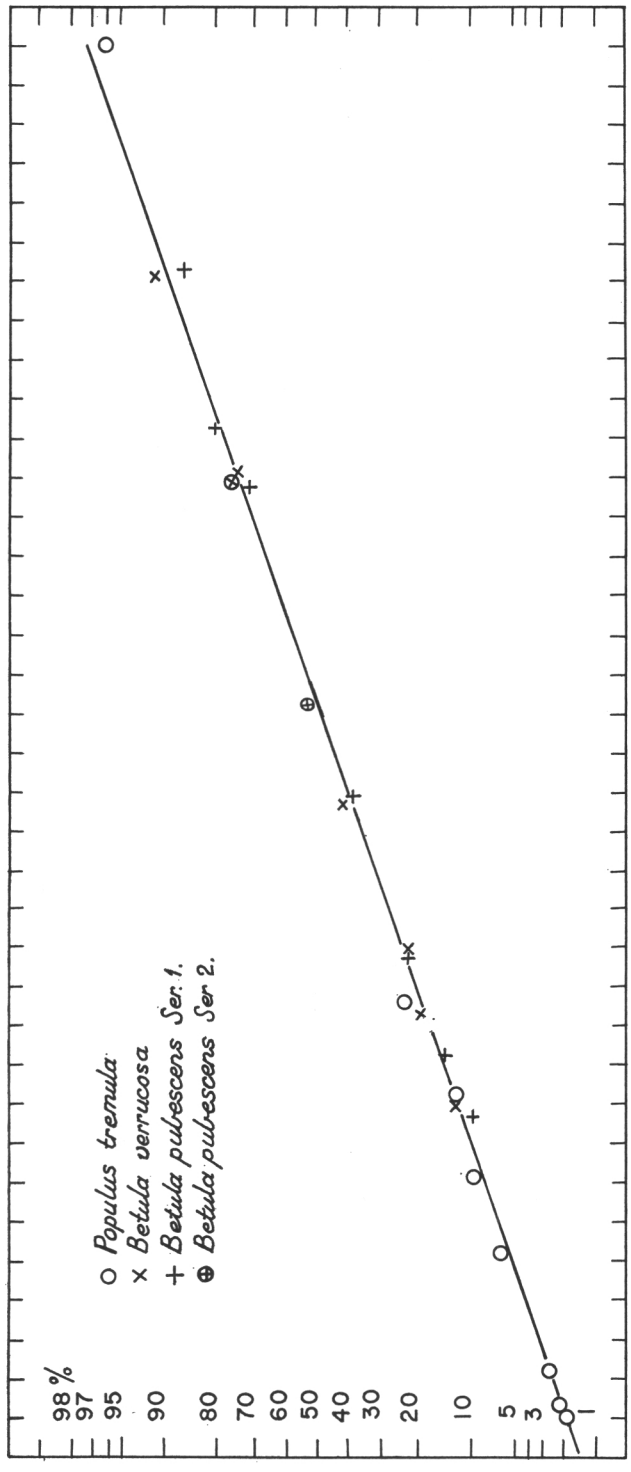

Fig. 12. The regression of the rate of progress v(T) on temperature shown as a cumulative function of a normal frequency distribution, the mean point of which is $\bar{x} = +18.2$°C, $\bar{y} = +14.0$ p.u./h.

preted as a cumulative function of the normal frequency distribution. This raises, of course, the question as to whether this finding has any deeper plant physiological significance. However, the present study fails to provide an answer to this question.

The examination carried out now is complemented by investigatory results obtained at a late phase of this study by going into the meiosis of *Larix sibirica* and *Larix Gmelini* (pp. 27—29).

Table 6. Data on the rate of progress of the active period v (T) of *Larix species* under different constant temperatures (T)

Experimental object	Experim. temperature T	Time in days		v (T) p.u./h = $5 \frac{h_{10}}{h_T}$	% of 28
		h_{10}	h_T		
Larix sibirica, meiosis in microspore mother cells, MI → MII	0.3	1.0	8.0	0.625	2.23
	1.6	1.0	5.8	0.865	3.10
	2.1	1.0	4.5	1.110	3.94
	3.1	1.0	3.9	1.380	4.92
	4.0	1.0	3.0	1.670	5.95
	5.1	1.0	2.5	2.000	7.15
	6.1	1.0	2.2	2.28	8.15
	7.0	1.0	1.6	3.130	11.16
	8.0	1.0	1.0	5.0	17.9
	9.6	1.0	1.0	5.0	17.9
Larix Gmelini, ... meiosis in microspore mother cells, MI → MII	1.6	0.8	4.5	0.885	3.15
	2.1	0.8	4.6	0.870	3.11
	3.1	0.8	3.8	1.050	3.75
	4.0	0.8	2.8	1.430	5.10
	6.1	0.8	2.0	2.00	7.15
	7.0	0.8	1.4	2.86	10.20
	8.0	0.8	1.5	2.68	9.60
	9.6	0.8	0.9	4.45	15.45

The rates of progress of the active period reckoned on the basis of this material are seen in Table 6, the last vertical column but one. By placing these data in Fig. 11 we could find out how they fit into the picture obtained in the foregoing. However, for the sake of clarity and comparison, a separate graph has been constructed (Fig. 13). Thus, the straight line drawn in the dot graph has not been fitted to this graph but rather it has been obtained by shifting the regression line as is from Fig. 12 into this figure. Fig. 13 demonstrates that the regression arrived at earlier well explains the evidence accumulated later.

It is important to establish which of the goals set have been reached but it is at least equally important to establish which of them have not been reached. The following limitations, in particular, call for attention.

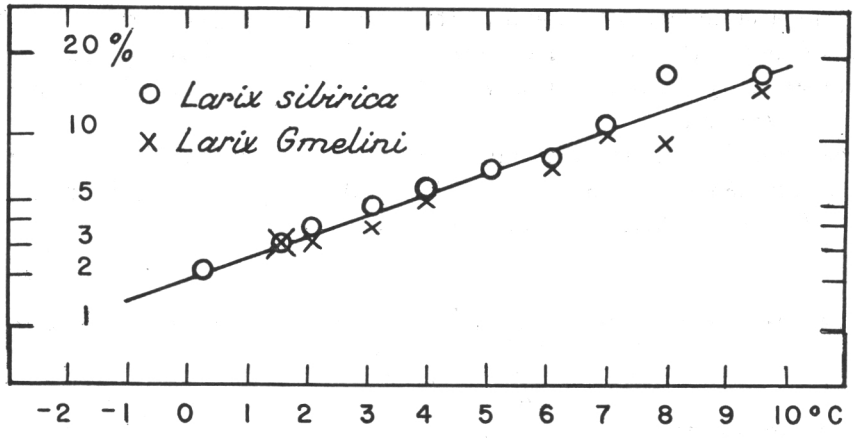

Fig. 13. *Larix sibirica* and *Larix Gmelini*. The regression of the rate of progress of the active period on temperature shown as a cumulative function of the normal frequency distribution.

The unit of the cycle interval of the active period is, according to our definition, different for different tree species, individual trees and even for the different parts of the active period of an individual tree.

In the foregoing (p. 28), it has been established, for instance, that at a constant temperature of 2°C, the meiosis in the microspore mother cells of *Populus tremula* progresses from MI to MII much more rapidly than the meiosis in the microspore mother cells of *Larix sibirica* and *L. Gmelini*, but we do not know the reason for this difference. It may be speculated that the physiological events between MI and MII are about the same, numerically, in all of them but that in *Populus tremula* they occur more rapidly than in the *Larix* species. Or, conversely, that the physiological events are equally rapid in all of them, but that there are fewer of them in *Populus tremula*. In reality, there may be differences in both respects.

The matter becomes less complicated, however, when examination is confined to one tree species. If we establish, for instance, that in *Populus tremula* there are significant differences between individual trees in the time lapses measured between the meiotic phases MI and MII at a constant temperature, it may be realistic to assume that the physiological events involved are the same and that the difference lies expressly in rapidity of occurrence. At all events, an assumption of some kind seems necessary in this respect so that we can make progress in our examination. The assumption may later prove wrong but even that would be tantamount to a step forward.

It would, without doubt, be interesting to clarify as to whether the rate of progress of the active period of an individual tree should be thought of

as being constant in all the different phases of the active period. In the foregoing, it has been stated that the many different physiological events comprising the active period are incomparable with one another. On account of this, the whole question of whether the rate of progress is constant in all the phases of the active period seems at first to be illogical. However, it should be remembered that there is a possibility that the physiological events involved are composed of basic phenomena that are more similar. If this is taken into consideration, the question will no longer be illogical.

In this study, meiosis in the microspore mother cells has frequently been chosen as an investigatory object. Also in connection with the present difficult problem, the meiosis in the microspore mother cells affords interesting evidence. In the *Larix* species, the microspore mother cells reach the end of the active period (and, consequently, dormancy) in diplotene, in the middle of meiosis. An interesting observation is that at a given constant temperature, the meiotic phases preceding dormancy take up a very much longer time than do those following it (Fig. 14). The difference is so large as to attract attention even though there is no reason to anticipate that at a given constant temperature the length of all the meiotic phases would be the same or even nearly the same.

In connection with this phenomenon, it is interesting to compare the meioses of *Larix sibirica* and *Picea Abies* with each other (Figs. 14 and 15). In the genus *Picea*, the meiosis in the microspore mother cells occurs entirely after dormancy. Attention is drawn by the observation that for *Larix sibirica* and *Picea Abies* the p.u. sums covering the postdormancy phases are of the same class of magnitude, whereas the predormancy phases in *Larix sibirica* are about three times longer than the same phases in *Picea Abies*. Particularly, in consideration of the fact that the meioses in the microspore mother cells of *Larix sibirica* and *Picea Abies* are largely similar in other respects, it is tempting the speculate that the progress of the active period of meiosis of the *Larix* species is slower at the very end than at the beginning of the active priod. At the end of the active period, slightly before the onset of dormancy, the water content of living cells decreases and the concentration of different soluble sugars increases. This is apparently designed to ensure a better frost hardiness. When the cell sap has a consistency of this kind, it is perhaps conceivable that it retards meiosis in which chromosome movements play an important role. Accordingly, speculation along these lines, even if vague, emphasizes that there is no reason to think that at a constant temperature the absolute rate of progress of the active period, even with regard to the basic phenomena, would be the same in all the phases of the active period.

In conclusion it should be pointed out that the limitations attending the application of the rate of progress of the active period, which have been

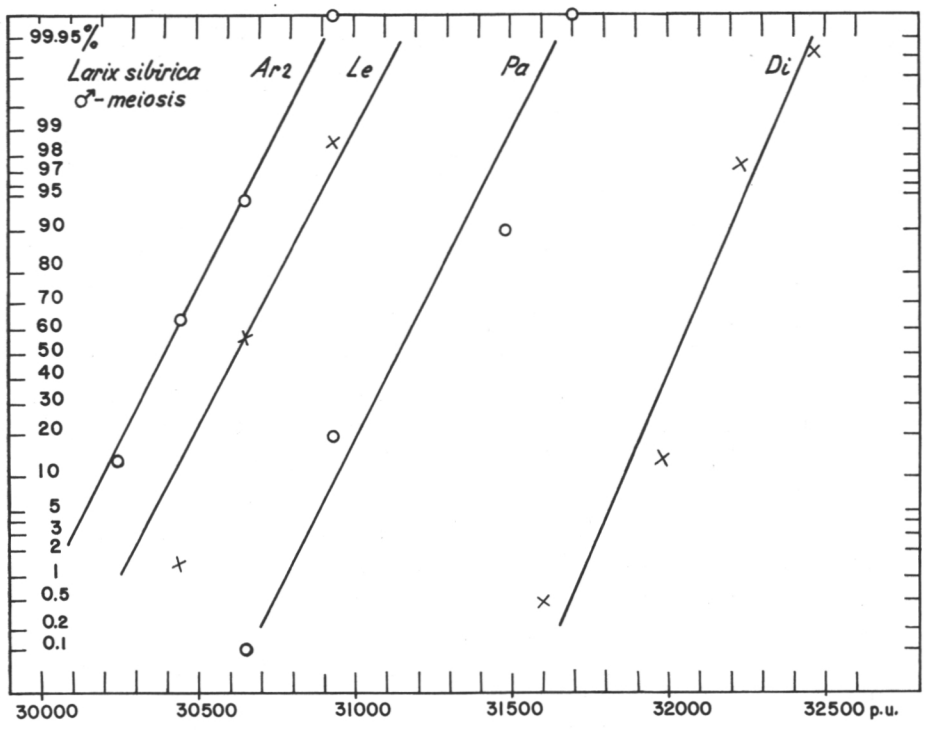

Fig. 14a. Meiosis in microspore mother cells of *Larix sibirica*, tree No. 14, sample plot 8, Punkaharju. Fixed in nature autumn 1968 and spring 1969. The cumulative frequency distribution of microspore mother cells in different meiotic phases. P.u.-sums are based on temperatures measured in a Stevensen-screen above canopy in this stand. Legend: Ar2 = archesporial phase 2 (the chromatin is shifting towards the center of the microspore mother cell), Le = leptotene and zygotene, Pa = pachytene, Di = diplotene, Dia = diakinesis, MI = metaphase I, AI = anaphase I, TI = telophase I, I = interphase, Pr = prophase, MII = metaphase II, AII = anaphase II, TII = telophase II, and Tr = tetrads.

Fig. 15. Meiosis in microspore mother cells of *Picea Abies*, tree No. 110, sample plot LII, Punkaharju. Fixed in nature spring 1970. The cumulative frequency distribution of microspore mother cells in different meiotic phases. P.u.-sums are based on temperatures measured in a Stevenson-screen above canopy in this stand. Scale frequency net. Legend: Le = leptotene and zygotene, Pa = pachytene, Di = diplotene, Dia = diakinesis, MI = metaphase I, AI = anaphase I, TI = telophase I, I = interphase, Pr = prophase, MII = metaphase II, AII = anaphase II, TII = telophase II, and Tr = tetrads.

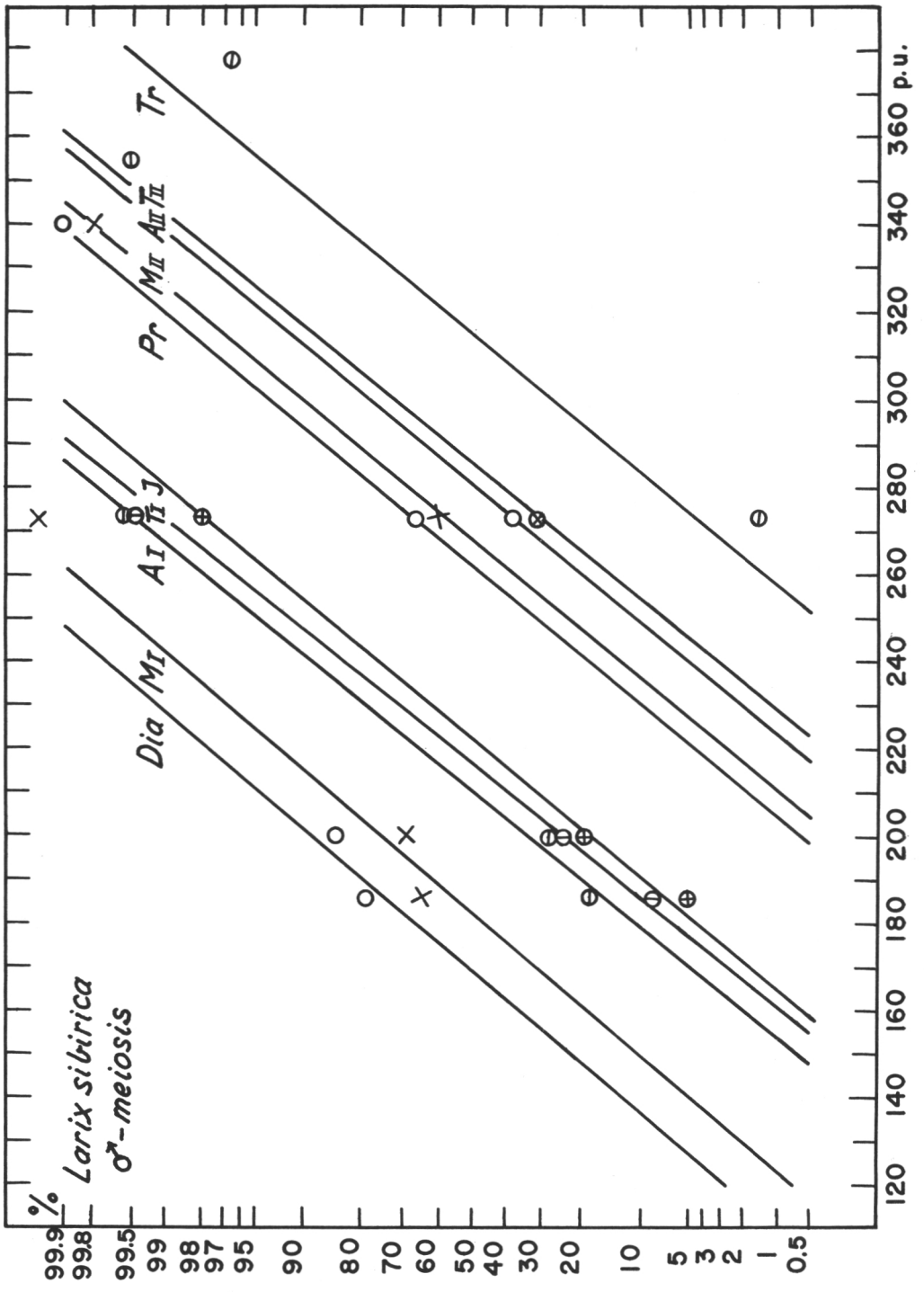
Larix sibirica
♂-meiosis
%
99.9
99.8
99.5
99
98
97
95
90
80
70
60
50
40
30
20
10
5
3
2
1
0.5
120
140
160
180
200
220
240
260
280
300
320
340
360 p.u.
Dia
M I
A I
H J
Pr
M II
A III
T III
Tr

Fig. 14 b.

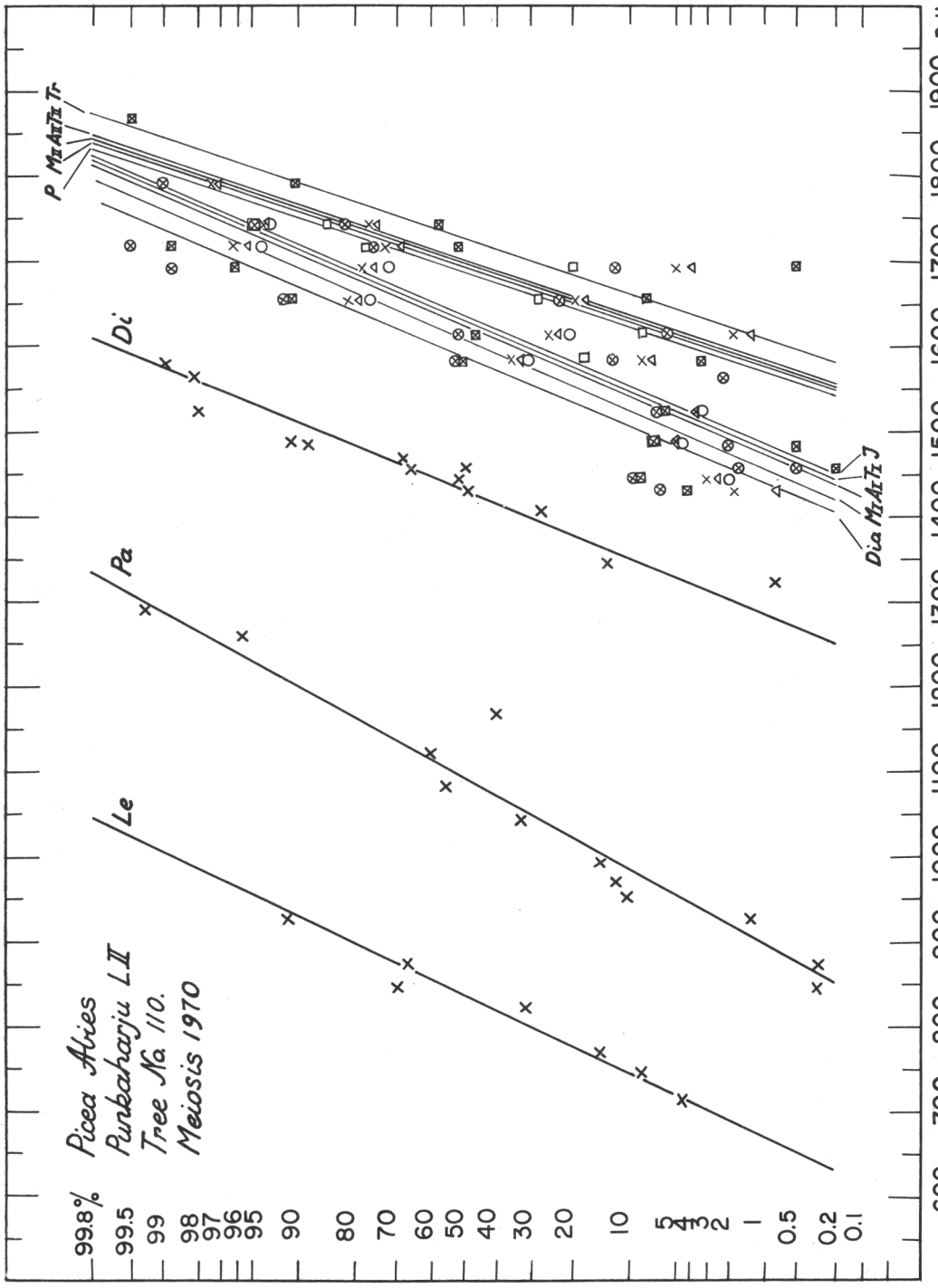
Picea Abies
Punkaharju L II
Tree No. 110.
Meiosis 1970
Le
Pa
Di
P
Mi Ai Ti Tr
Dia Mi Ai Ti J
p.u.
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
99.8%
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
0.5
0.2
0.1

Fig. 15.

touched upon above, do not affect the obviously most significant experimental result of the present investigation, i. e. that the regression of the rate of progress of the active period on temperature is the same for all the genera, species, individual trees and the different parts of the active period investigated in this study. Consequently, this regression is very interesting from a theoretical as well as from a practical point of view. In order to make the information furnished by the regression readily available, it has been tabulated in Table 7 at intervals of 1/10 of a Celsius degree and 1/100 of the rate of progress of the active period.

Table 7. Rate of progress of the active period at different constant temperatures

Full degrees °C	Decimal fractions of degrees									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	P.u./h.									
—3	0.24	0.23	0.22	0.22	0.21	0.20	0.20	0.19	0.19	0.18
—2	0.32	0.31	0.31	0.29	0.28	0.28	0.27	0.26	0.25	0.25
—1	0.42	0.41	0.41	0.39	0.38	0.37	0.36	0.35	0.34	0.33
—0	0.57	0.55	0.53	0.52	0.50	0.49	0.48	0.46	0.45	0.43
+0	0.57	0.59	0.60	0.63	0.64	0.66	0.67	0.69	0.71	0.73
1	0.76	0.77	0.78	0.81	0.84	0.85	0.87	0.91	0.94	0.97
2	0.98	0.99	1.01	1.05	1.08	1.11	1.12	1.13	1.18	1.23
3	1.25	1.27	1.29	1.33	1.39	1.40	1.43	1.46	1.48	1.51
4	1.57	1.60	1.62	1.68	1.71	1.76	1.79	1.85	1.88	1.90
5	1.96	1.99	2.02	2.07	2.13	2.18	2.21	2.27	2.30	2.35
6	2.41	2.44	2.52	2.55	2.60	2.66	2.72	2.77	2.83	2.88
7	2.91	3.00	3.05	3.11	3.16	3.25	3.30	3.36	3.39	3.47
8	3.56	3.61	3.67	3.75	3.81	3.89	3.95	4.00	4.09	4.17
9	4.23	4.31	4.37	4.45	4.54	4.62	4.70	4.76	4.81	4.93
10	5.00	5.10	5.15	5.26	5.35	5.43	5.54	5.60	5.68	5.80
11	5.88	5.96	6.05	6.16	6.22	6.36	6.44	6.50	6.64	6.72
12	6.80	6.92	7.00	7.08	7.23	7.31	7.39	7.50	7.59	7.73
13	7.84	7.92	8.04	8.12	8.23	8.37	8.43	8.57	8.68	8.76
14	8.93	8.99	9.13	9.24	9.32	9.49	9.55	9.74	9.80	9.94
15	10.08	10.14	10.30	10.39	10.53	10.64	10.75	10.89	10.98	11.14
16	11.20	11.34	11.48	11.56	11.73	11.82	12.01	12.06	12.24	12.32
17	12.46	12.57	12.66	12.82	12.91	13.08	13.16	13.36	13.44	13.55
18	13.69	13.83	13.97	14.06	14.22	14.34	14.48	14.56	14.70	14.84
19	14.92	15.09	15.15	15.32	15.43	15.54	15.68	15.79	15.93	16.02
20	16.18	16.27	16.41	16.52	16.63	16.80	16.86	17.02	17.11	17.28
21	17.36	17.47	17.61	17.70	17.84	17.92	18.09	18.20	18.26	18.40
22	18.51	18.65	18.76	18.87	18.98	19.07	19.25	19.32	19.43	19.57
23	19.63	19.74	19.88	19.96	20.10	20.16	20.30	20.44	20.52	20.64
24	20.72	20.80	20.94	21.00	21.14	21.25	21.31	21.42	21.53	21.59
25	21.70	21.81	21.87	21.98	22.09	22.12	22.26	22.37	22.40	22.51
26	22.65	22.71	22.76	22.90	22.96	23.02	23.13	23.24	23.27	23.38
27	23.49	23.55	23.58	23.72	23.80	23.83	23.88	23.97	24.08	24.11
28	24.19	24.30	24.36	24.42	24.47	24.56	24.61	24.67	24.72	24.81
29	24.86	24.92	24.98	25.03	25.12	25.17	25.23	25.26	25.31	25.40
30	25.45	25.51	25.54	25.59	25.65	25.70	25.73	25.79	25.82	25.87
31	25.90	25.96	25.98	26.07	26.10	26.12	26.15	26.21	26.26	26.29
32	26.32	26.35	26.40	26.43	26.46	26.52	26.54	26.57	26.60	26.66
33	26.68	26.71	26.74	26.77	26.80	26.82	26.85	26.88	26.91	26.94
34	26.96	26.99	27.05	27.06	27.08	27.09	27.10	27.13	27.15	27.16
35	27.19	27.23	27.24	27.26	27.27	27.29	27.31	27.33	27.34	27.36

The length of any cycle interval of the active period can now with the aid of Table 7 be expressed in period units. It is only necessary to know the time that elapses in this cycle interval at a given constant temperature. Figuratively speaking, the length is equal to the rate of progress multiplied by the time. If, for instance, the time measured from the opening till the closing of the female catkins of *Pinus sylvestris* at a constant temperature of 13°C is 178 hours, the length of this cycle interval (receptive interval) expressed in period units is 178 hours × 7.84 p.u./h. = 1 400 p.u. The same result is obtained irrespective of which constant temperature between about 5 and 25°C is chosen for the measurement of this cycle interval. The same result is obtained at a varying temperature. In this case, the time has to be divided into periods so brief that the temperature during each period can be regarded as constant. For example, periods of 1 hour are suitable. Where the time is divided into periods of 1 hour, the length, in period units, of a given cycle interval is obtained by adding up those rates of progress (p.u./h.) that correspond to each hour's mean temperature. All the p.u. sums presented in this study and which are based on observations made in nature have been calculated in this way. The calculation of p.u. sums involves more work than, for instance, the calculation of degree hours (d.h.) or degree days (d.d.). Where a large number of p.u. sums pertaining to long cycle intervals are to be calculated it is most practical to handle the matter by means of a computer. This procedure was used, for instance, in the present study.

Although we have assigned each test object an individually defined unit for the cycle interval of the active period we can now draw the following two important conclusions:

1. In all the tree species now investigated and in the individual trees of the same species, the rate of progress of the active period depends in the same manner on temperature (Fig. 11, p. 31), since the regression comprises several tree species and several individual trees.

2. In all the phases of the active period, the rate of progress of the active period depends in the same manner on temperature (since the regression comprises different phases of the active period, of which one portion is representative of the first and another, of the second half of the active period).

This, of course, raises a more far-ranging question: how wide, taking all things into consideration, is the application area of the results obtained? As a matter of fact, the question itself supplies the answer, because it is obvious that it can never be comprehensively answered. At the moment, the main thing is that on the basis of investigations concerning a few tree species, a certain model has been created of the regression of the rate of

progress of the active period on temperature. As long as experimental evidence does not clearly contradict this model, it can simply be assumed that the model is representative of, for instance, all forest trees in temperate climates. If or when evidence contradicting the model accumulates, the model must be corrected accordingly. For instance, restrictions can be made with regard to the selection of tree species. Also, at a later stage of the investigation when new evidence will have accumulated, the model may be discarded and a new and better one created. And it is only to be hoped that this procedure proves successful in the endeavours to advance the progress of research in this field.

In the foregoing, attention has been paid to the general form of the regression of the rate of progress of the active period on temperature, which has been found to agree to a surprising degree with the general form of the cumulative function of the normal frequency distribution. This has, amongst other things, the significant advantage that the entire regression can be expressed accurately by three parameters: the coordinates of the mean point $x = 18.2°C$, $y = 14.0$ p.u./h. and the standard deviation 8.7°C (Fig. 12, p. 32).

However, it may be even more important to pay attention to certain conclusions derived from the general form of regression. Thus, in the first place, when expressed in the form of a graph, regression is not an optimum curve which at a given temperature or temperature range would reach its maximum value and at temperatures higher and lower than this temperature or temperature range would decline steeply. On the contrary, the higher the temperature, the higher, in principle, is the rate of progress of the active period; however, at high temperatures, the rate of progress approaches a given upper limit which it does not exceed. It does not make any difference whether each of those physiological events that are included in the active period and occur at low temperatures in nature has a certain individual tolerance limit, and that at temperatures exceeding this limit, disturbances occur and that they increase in number and intensity with the degree to which the tolerance limit is exceeded. Also at low temperatures, below —3°C or so, there are disturbances, in that freezing of cells occurs.

Another important conclusion derived from the general form of the regression is, as mentioned above, that there does not exist any threshold value below which temperatures would be ineffective with regard to the progress of the active period. The circumstance that live cells in their active period are easily damaged by low and by high temperatures is a question in itself and not an exception to the conclusion that has now been reached. There is every reason to anticipate that in the progress of the active period those meristems that do not become damaged at a temperature of, for instance, —2° or —3°C, conform to the general regression arrived

at above. As a result of this, the threshold value question, which has been widely discussed in phenology, loses its physiological significance even if threshold values exclusively from the point of view of heat sum calculation technique continue to be of certain interest.

Previous Studies

In the last two decades, several noteworthy studies have been published which clarify in particular how, in forest tree seedlings, the termination of the annual height growth and the induction of the terminal bud set depend on the climatic factors (cf., for instance, Vaartaja 1959, 1960, Wareing and Black 1958, Robak 1957, 1962, Holzer 1966, Dietrichson 1964, Dormling et al. 1968, Magnesen 1969, 1971, Roche 1969, 1970). Most of the conclusions reached in these studies emphasize the significance of day length (photoperiodism) as a factor contributing essentially to the termination of growth.

At first sight, these conclusions appear to be in conflict with the results introduced in the present study, but this need not necessarily reflect the true situation. The conflict may be due to a different approach to the problem or to the fact that the mapping out of this field of knowledge is still deficient. It is possible that as our knowledge increases, the conflict will gradually decrease.

As regards the approach to the problem, it should also be emphasized that growth termination and bud set are not synonymous with the termination of the active period. They must not be identified with one another. However, growth termination and bud set are among those physiological phases of the active period which in accordance with the cycle model constructed in the present study could, at least at first sight, be expected to be controlled primarily by the time-temperature factor (expressed e.g. as a p.u. sum) and not by day length. Thus, at this point, there is a certain conflict of ideas.

It is obvious, a priori, that day length cannot alone to any appreciable degree explain the annual variation observed in the progress of the active period in nature because, with regard to a given natural tree population, there is hardly any annual variation in day length.

On the other hand, in a phytotron and in other controlled environments it is possible to produce conditions that may differ greatly from one another in respect of day length (photoperiod). In the investigations referred to above, this method was employed and it has been established that photoperiod plays an important role in growth termination and bud set. These findings are of primary importance in programming the ever-increasing

growing of forest tree seedlings in green houses (including plastic green houses). On the other hand, the question of to what extent these findings can be extended to apply in the interpretation of natural phenomena remains largely open. The essence of the question consists in to what extent the reactions measured in phytotrons and greenhouses are homeostatic.

The influence exercised by photoperiodism on growth termination comes most distinctly to light when 1-year old seedlings are investigated. In the present study, however, mature trees have been the object of study. This might be of considerable importance. Nienstaedt (1966, p. 379) has reached the following conclusion: »Long photoperiods compensate in part for lack of chilling in all the plant material studied and markedly lengthen the growth period of young seedlings. This latter effect decreases with the age of the plants — in 4-year old (2-2-1) plants the effect is very minor and by the time the plants have gone through 7 periods of elongation growth, the effect is totally absent». Hagner (1970b, p. 17) in his studies on the services afforded by the different physiological parameters for the assessment of the degree of progress of the active period (annual growth rhythm) establishes that the assessments pertaining to the uncovering of the terminal buds correlate poorly with the results produced by other methods.

Furthermore, it should perhaps be emphasized that growth termination and bud set are point events (cf. page 7) which are difficult to measure accurately. A given physiological phase of the active period is considered to be a good point event if, in respect of each of the observational objects, it can be ascertained practically beyond dispute whether or not the phase involved has been passed through. Neither growth termination nor bud set meets this condition satisfactorily. For instance, in the growth termination phase, the daily height growth approaches asymptotically zero and, therefore, it is not possible in every case to make accurate observations on whether or not height growth of a given seedling has terminated. The same applies to bud set in so far as size of the bud is concerned; it should further be added that after the bud has attained full size, the formation of new leaf initials and the morphological differentiation in general continue for a long time in the bud (cf. Leike 1965, p. 476: »Eine Beurteilung der Knospen nur nach dem äusseren Erscheinungsbild muss jedoch zu falschen Schlussfolgerungen bei der Bewertung der Experimente führen», and Owens 1968, p. 277: »This means that the growing season, or at least the season of highest activity within the bud, is 9 months long and that our usual criteria of bud set and bud burst which we refer to as »growing season» may often to be inaccurate».) Also, more attention should perhaps be paid to the consideration that in the development of forest tree seedlings, the formation of the first terminal bud, which terminates the continuous flush phase, is a phenomenon that belongs to the life cycle rather than to the active period. The first terminal bud of

a seedling is in many respects in an exceptional position as compared with buds developed later (cf. e.g. Romberger 1969, p. 3—4).

Despite the fact that there is a certain inconsistency, expressly as regards the significance of photoperiodism, between the results pertaining to the investigations referred to on page 42 and those relating to the present study it should be emphasized that the results involved agree, nevertheless, in many other respects.

The studies published recently by Magnesen (1969, 1971) may serve as an example here. He employed an ingenious research method and had the use of equipment especially constructed to meet the needs of the study.

Let us first study 1969, Fig. 3 on p. 19 and Fig. 5 on p. 24 and, further, pp. 22—25. It can be seen that in both series of tests, the local Norwegian provenience conformed to the principle presented. In the first series of tests, the proportion of seedlings that had formed the terminal bud rose in the temperature conditions of a warm summer to 50 % about 6 pentads earlier than in the temperature conditions of a cold summer. Also in the other series of tests, in which the illumination was stronger, the corresponding difference was 6 pentads (as pointed out on page 11, the time required for 50 % of the seedlings to form the terminal bud, serves perhaps best as a criterion for the comparison). In a light-climate corresponding to 48°N, lowland proveniences 00/47 Lankowitz, Austria (about 500 m. above sea level) and 33 Toplita, Rumania (about 800—900 m. above sea level) originating from about this parallel of latitude behaved as follows: in each of them, the proportion of seedlings that had formed the terminal bud rose in the temperature conditions of a warm summer to 50 % much earlier than in the temperature conditions of a cold summer. Proveniences originating from higher up in the mountains showed smaller differences, but it is to be noted that here the difference in light conditions between the dimly lit growth chamber and the very intense light of the natural habitat is most drastic.

In the latter study, Magnesen obtained results which were perhaps even closer to the conclusions reached in the present study. In his final review of the results, p. 263, Magnesen states, amongst other things, that the growth chamber experiments performed so far seem to indicate that the time of initiation of the uncovering of the terminal buds is controlled primarily by photoperiod. In the subsequent time it seems, however that the formation of the terminal bud depends completely on temperature conditions. Thus, he continues, it is possible that plants in so far as the uncovering of the terminal bud is concerned do not react to the thermal factor until photoperiod has decreased below a certain minimum in the autumn.

Comparison of Experimental Results with Conditions in Nature

Introduction

All the investigatory results presented in the previous chapter concerning the rate of progress of the active period are based on laboratory experiments conducted under conditions that in many respect differ drastically from the natural habitat of the study objects. For instance, the experimental twigs were cut from mother trees and the majority of experiments were conducted in a dark room or dark incubators. Consequently, the results obtained cannot without any further consideration be applied to events occurring in nature. At least, it is necessary to clarify by means of appropriate tests whether in nature the rate of progress of the active period depends on temperature and time in the same way as it does under the experimental conditions described above.

In this connection it should, however, be noted that the twigs used in the experiments were taken immediately before the experiments were begun, from healthy trees growing in natural surroundings, and that the experiments lasted a relatively short period of time. Thus, the research material was not actually grown under controlled conditions but was removed from nature to controlled conditions for observation during a short period of time. When research material must be kept under controlled conditions for several months or a whole growing season or several years, the research worker is likely to be faced with problems of a very different type, i.e. problems concerning test technique which are difficult to surmount. Above all, it will also be necessary to control all environmental factors not actually part of the experiment, e.g. humidity and light, so that the natural needs of the experimental material in respect of these factors be satisfied. The most important of these factors is light, which under experimental conditions is often dimmer than in nature and has a different spectrum, a circumstance that in experiments of long duration easily produces artifacts ascribable primarily to starvation of the experimental material.

Concept of the Time-Temperature Control of the Active Period

Before the comparison is started it seems necessary to explain in greater detail what in this study is meant by stating that in nature the progress of the active period appears to be controlled almost exclusively by time and temperature. At first, this conception seems to be in conflict with many a general observation and experience. For instance, the onset, progress, and cessation of the anthesis (male flowering) of *Pinus sylvestris* are also clearly influenced by wind, relative humidity of the air, and rain. Let us study this example closer.

In calm weather, the transpiration of moisture from the pollen sacs of the anthers is slower than in windy weather, which delays the dehiscence of the pollen sacs. Furthermore, in calm weather, a large portion of the released pollen remains in the sacs or drops on the anthers down below instead of dispersing. This is generally the case when the wind velocity is below 1 m./second but even when the wind velocity is about 2 m./second, anthesis is delayed, at least initially.

The effects produced by changes in the humidity of the air are somewhat similar (cf. S a r v a s 1962, p. 57): 60 % may be regarded as the upper limit for humidity. When the relative humidity is higher, the dehiscence of the pollen sacs is delayed. Rain dampens the sacs, thus delaying the dehiscence. Furthermore, heavy rain washes off pollen grains to the ground and they are in this way wasted.

Table 8. An illustration of the method employed in the calculation of the daily and cumulative values of the pollen catches. *Pinus sylvestris*, Punkaharju, sample stand XVL, 1968

Day and month	Point No.				Cum. sum	Cum. %	Hours				Catch per Sq.mm. per p.u.
	M1	M2	M3	Average			24.00	0.00	Difference	Mean	
	Pollen/sq.mm./day						P.u.-sum				
5. 6.	9.36	2.08	8.84	6.76	6.76	0.17	5 482	5 184	298	5 333	0.02
6. 6.	31.2	7.80	15.6	18.2	25.0	0.64	5 844	5 482	362	5 663	0.05
7. 6.	39.5	19.8	39.0	32.8	57.7	1.47	6 135	5 844	291	5 990	0.11
8. 6.	88.4	30.2	66.0	61.5	119	3.04	6 366	6 135	291	6 251	0.27
9. 6.	210	127	187	175	294	7.50	6 560	6 366	194	6 463	0.90
10. 6.	33.3	23.9	16.1	24.4	318	8.12	6 736	6 560	176	6 648	0.14
11. 6.	412	484	·	448	766	19.6	6 881	6 736	145	6 809	3.09
12. 6.	319	331	·	325	1 991	27.8	7 095	6 881	214	6 988	1.52
13. 6.	1 233	1 272	·	1 253	2 345	59.8	7 399	7 095	304	7 247	4.12
14. 6.	1 064	1 127	·	1 095	3 440	87.7	7 717	7 399	318	7 558	3.44
15. 6.	269	399	·	348	3 788	96.6	8 024	7 717	307	7 871	1.13
16. 6.	44.6	26.5	·	34.1	3 822	77.5	8 262	8 024	238	8 143	0.14
17. 6.	15.6	10.9	23.9	16.8	3 839	97.9	8 545	8 262	283	8 404	0.06
18. 6.	16.6	10.9	18.2	15.3	3 854	98.3	8 831	8 545	286	8 688	0.05
19. 6.	43.2	30.7	39.5	37.8	3 892	99.3	9 244	8 831	413	9 038	0.09
20. 6.	8.84	5.72	14.5	9.71	3901	99.5	9 695	9 244	451	9 470	0.02
21. 6.	6.24	39.0	12.5	19.2	3 921	100	10 126	9 695	431	9 911	0.04

The effect of wind and humidity on anthesis is, however, of a temporary nature. It is most pronounced during the first 24 hours. If the calm and humid weather continues the following day, the effect will abate, and if it does not continue, a number of pollen sacs will open and pollen will disperse in greater abundance than would have been the case had the day before been more favourable from the point of view of anthesis.

The matter is illustrated by Figs. 16 and 17 demonstrating the catch rates and the cumulative amounts of pollen measured by self-recording pollen samplers (cf. S a r v a s 1968, pp. 23—26) in Punkaharju Experimental Forest XLV in 1968. For added clarity, Table 8, p. 46 shows the computations involved. The catch rates, computed as 24-hour means, are shown in the last vertical column, and the cumulative amounts, computed as percentages of the total pollen catch, in the 7th vertical column from the left. When studying the table, attention is, without doubt, drawn by the blank space (6 days) in the 4th vertical column. This blank is due to one of the pollen samplers getting out of order at the beginning of the week involved (this goes to show that the measurements should be carried out with at least three pollen samplers).

Let us first study Fig. 16 in which the horizontal axis shows the cumulative p.u. sum calculated from the beginning of the year and the vertical axis

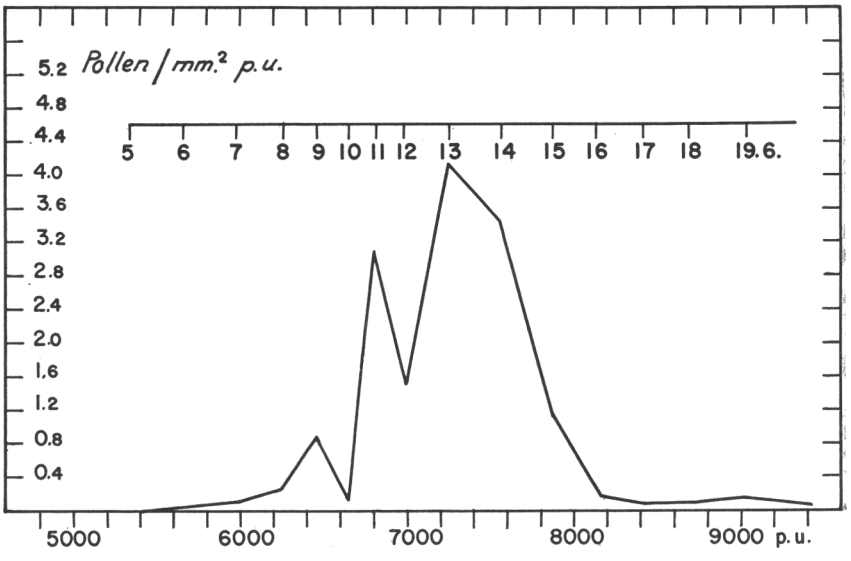

Fig. 16. The daily pollen catch rates in Punkaharju *Pinus sylvestris* experimental stand No. XVL in the summer of 1968. The horizontal axis shows the p.u. sum reckoned from the beginning of the year and the vertical axis, the number of pollen grains per sq.mm. and p.u. The readings are placed at the average p.u. sum of each day. The calendar time is seen above the diagram.

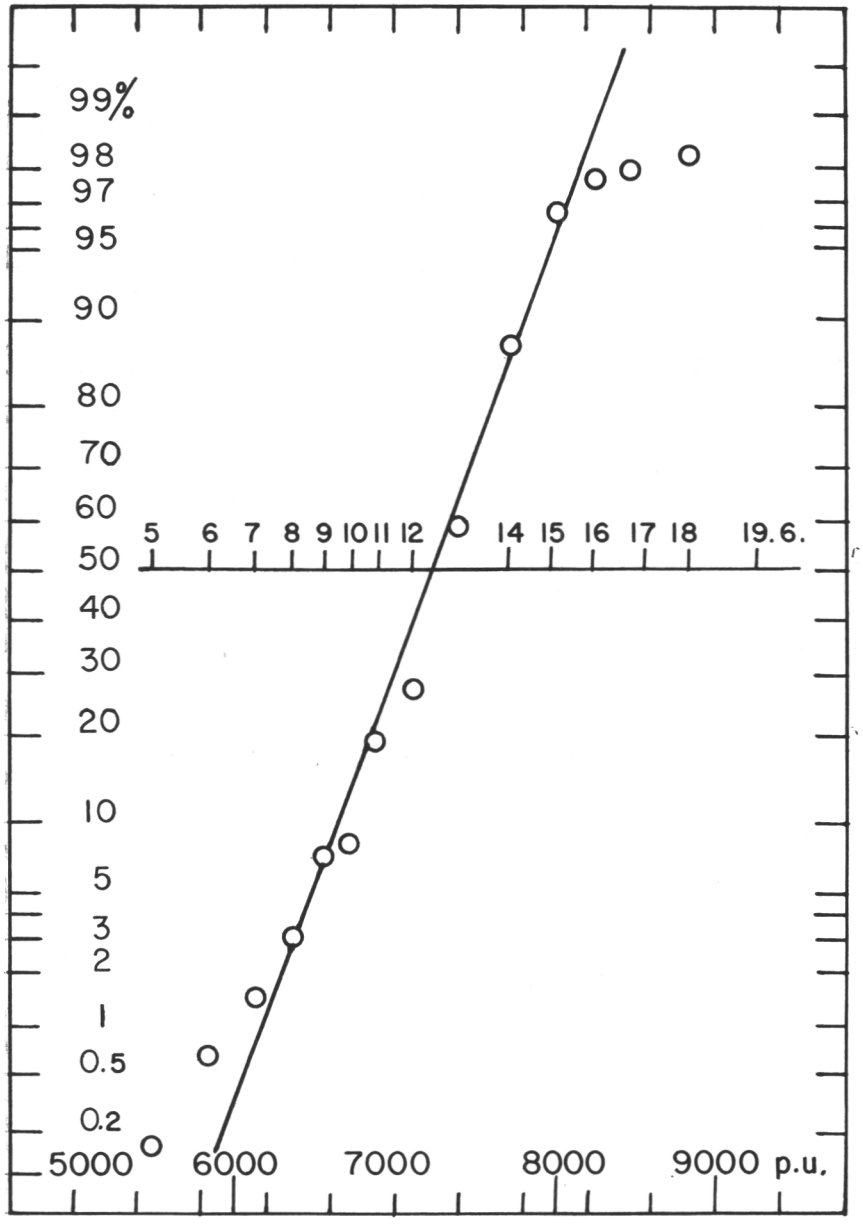

Fig. 17. The cumulative frequency distribution of daily pollen catches (pollen/mm.²/p.u.) of *Pinus sylvestris* pollen in sample plot XLV, Punkaharju 1968. Scale: frequency net. On the horizontal axis the cumulative p.u.-sum calculated from the beginning of the year. In the middle of the diagram the calendar time.

the daily catch rates computed as 24-hour means by dividing the number of grains caught per mm². within 24 hours by the p.u. sum of the day involved. Furthermore, the diagram shows the calendar days.

If the progress of the active period depends on time and temperature alone, it is to be anticipated that the graph showing the pollen catch rates takes the graphic form of the normal frequency distribution. In the illustration, this anticipation has materialized to a certain degree; however, considerable divergences occur, especially, at the 10th and 12th day which, of course, prompts the question as to the cause for this.

Table 9 shows measurements made by the Meteorological Institute's Synoptic Station at Punkaharju concerning wind and humidity. The station is located at about 600 m. from the Experimental Forest XLV. From the table it can be seen that on the 10th day, the wind was light (on an average, 2 m./sec.), the relative humidity of the air was high (on an average, 85 %) for 24 hours and, furthermore, at midday there was a fairly heavy thundershower (2.6 mm.). It had also rained the day before and even more heavily (3.6 mm.) but the rain came fairly late (between 16—17 h.), by which time the majority of the pollen sacs that had opened during the day had been emptied. The following day was very favourable for pollen dispersal, because the weather was sunny and the wind moderate. The 12th day, too, was sunny, but the speed of wind was only slightly above 2 m./sec. Thus, it seems that the divergence from the anticipated form of the normal curve

Table 9. Data on the atmospheric conditions in Punkaharju between June 5—June 21, 1968. The readings have been obtained from the Punkaharju Synoptic Station of the Meteorological Institute located about 600 m. form the Experimental Stand XLV

Day and month	Hours								Precipitation	Hours	
	2	8	14	20	2	8	14	20		8	20
	Humidity %				Wind m./sec.					mm.	
5. 6.	56	59	37	48	2	2	5	3		—	—
6. 6.	72	66	38	66	2	2	4	5	19—20	—	<0.1
7. 6.	88	71	42	57	4	4	6	4	23—24	—	—
8. 6.	96	79	44	52	2	3	3	3	0.0—3 23—24	5.9	—
9. 6.	80	65	54	93	3	3	4	3	16—17	0.4	3.6
10. 6.	95	77	84	76	2	2	2	2	11— 2; 23—24	0.2	2.6
11. 6.	65	58	47	64	3	4	3	1		0.5	—
12. 6.	89	57	43	55	2	2	3	2		—	—
13. 6.	73	62	40	49	2	4	4	2		—	—
14. 6.	57	52	46	47	4	4	5	5		—	—
15. 6.	83	55	43	48	2	2	6	7	9—10	—	—
16. 6.	61	56	48	52	3	3	3	2		—	—
17. 6.	97	49	35	57	1	3	4	1		—	—
18. 6.	76	53	46	79	3	3	3	1	17—18	—	0.3
19. 6.	63	62	55	51	3	4	3	4		—	—
20. 6.	64	65	46	60	3	4	4	1		—	—
21. 6.	95	76	59	64	2	2	3	3	21—24	—	—

would, in the first place, be caused by wind but that rain, too, should be considered a factor.

Fig. 17 may even provide a clearer picture of the influence exercised by wind and rain. In this diagram, too, the horizontal axis shows the cumulative p.u. sum reckoned from the beginning of the year. The ordinates show, at 24-hour intervals, the cumulative amounts of the pollen catches, expressed as percentages of the total catch. In the centre of the figure, the calendar time is shown. This graph shows even clearer than the previous one that the cumulative amounts of the pollen catches generally conform to the normal frequency distribution, the mean value of which is about 7 240 p.u. and the standard deviation about 440 p.u. (variation coefficient 0.06, cf. Sarvas 1967, pp. 223—224). However, it can also be seen immediately that at the beginning of the frequency distribution, the pollen catches are in overfrequency, and at the end, in underfrequency. The deviation from the normal frequency distribution at the beginning of the distribution may probably be ascribed to background pollen which at the flowering time is generally carried by southern winds from areas with a higher p.u. sum. At the end of the distribution, the deviation probably results from the fact that the last pollen grains adhering to the walls of the pollen sacs do not become detached until the anthers are completely dry and the wind is fairly strong.

In studying Fig. 17, most attention should, however, again be paid to the 10th, 11th, and 12th days. On these days, the cumulative percentage of the catch remains considerably below the fitted straight line. Wind, relative humidity of the air, and rain affect the progress of anthesis. At the same time, however, it can be seen that they do not appreciably affect the mean value of anthesis and not even the standard deviation of the frequency distribution. This is an important consideration. On the other hand, these factors do increase the dispersion of the dots from the fitted line and thus lessen its reliability (i.e. they broaden its confidence belt). Statistically, the effects of wind, relative humidity of the air, and rain may thus be included in the factors increasing the error variance.

In saying that the progress of the active period seems to be controlled primarily by the thermal factor, we actually mean that wind, relative humidity of the air, and rains do not appreciably affect it. Above all, we mean that the progress of the active period depends, more or less, on the entire physiology of the tree and all the environmental factors affecting it, but that time and the thermal factor jointly explain a high percentage of the annual variation found in the progress of the active period.

In our investigations, we have not yet advanced far enough to be in a position to examine, in detail, the annual variation in those cycle intervals of the active period that can be measured accurately. Figs. 18 and 19 throw

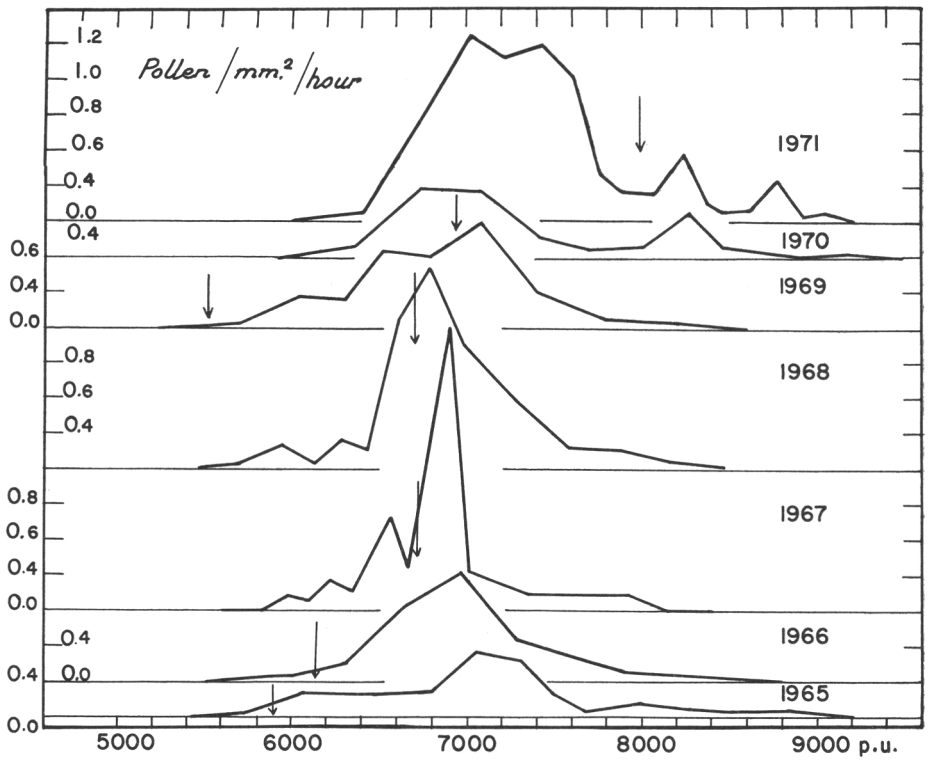

Fig. 18. *Pinus sylvestris*, Bromarv III. The frequency distribution of the p.u.-sums of the pollen caches between 1965 and 1971. The p.u.-sums are based on temperatures measured in a Stevenson-screen placed above the canopy in this stand. Scale arithmetic. The horizontal axis shows the cumulative p.u.-sum reckoned from the beginning of the year, and the vertical axis, the daily pollen catches per sq.mm./p.u. The arrows indicate the p.u.-sum on which the 10th June, 00 hours, has fallen in each of the years involved.

light, by means of examples, on this question. They show the pollen catches of *Pinus sylvestris* and *Picea Abies* measured in Bromarv experimental stands III and I in 1964—71. It can be seen that in the years involved, the pollen catches of these species were recorded almost exclusively within the same p.u. sum intervals (in the case of *Pinus sylvestris*, between 5 800—8 400 p.u., and in the case of *Picea Abies*, between 3 800—6 000 p.u.). On the other hand, in terms of calendar time, there are large differences between the different years. It is obvious that as a physiological clock the p.u. sum is much more serviceable than calendar time (or photoperiod).

Figs. 18 and 19 also illustrate what in the foregoing is meant by good synchronization of the different components of a biocoenosis. In 1964—1971, onset of the anthesis of *Pinus sylvestris* occurred immediately after the anthesis of *Picea Abies* was over. The overlapping portion was almost the

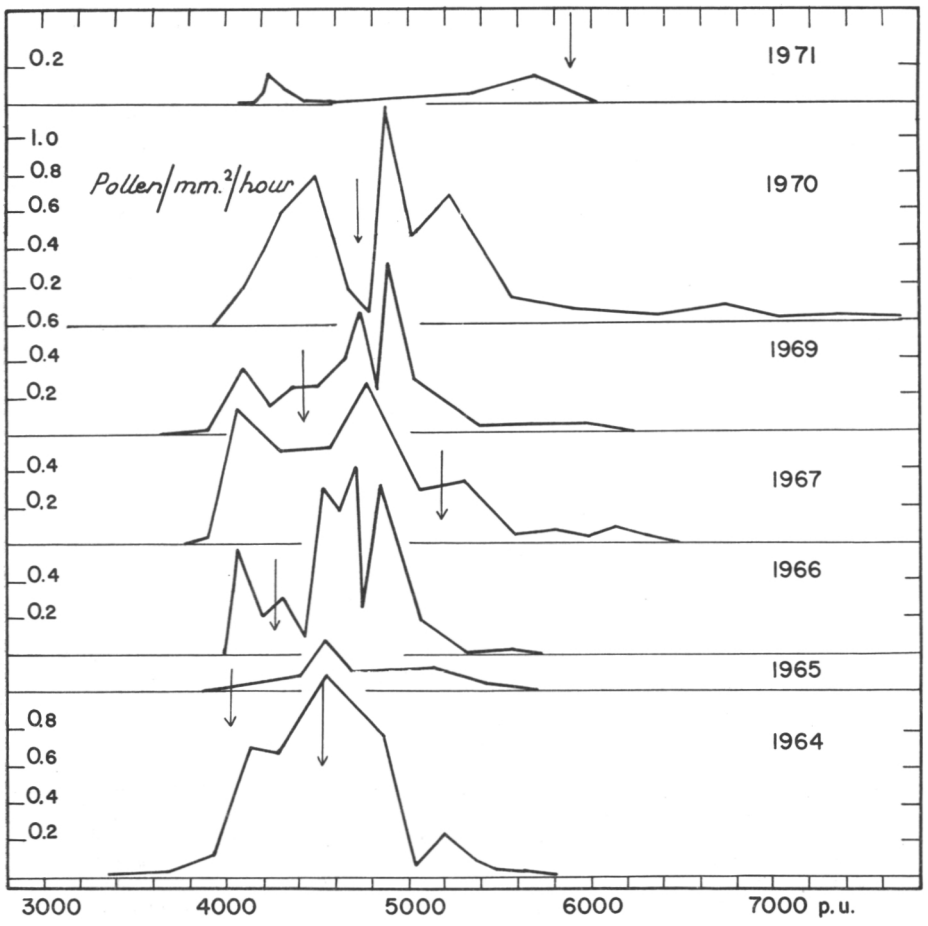

Fig. 19. *Picea Abies*, Bromarv I. The frequency distribution of the p.u.-sums of the pollen catches between 1964 and 1971. In 1968, *P. Abies* did not flower at Bromarv. The p.u.-sums are based on temperatures measured in a Stevenson-screen placed above the canopy in this stand. Scale arithmetic. The horizontal axis shows the cumulative p.u.-sum reckoned from the beginning of the year, and the vertical axis the daily numbers of pollen grains per sq.mm./p.u. The arrows indicate the p.u. sum on which the 1st of June, 00 hours, has fallen in each of the years involved.

same each year, about 5—10 % of the total *Picea Abies* pollen cloud. What has now been said of *Picea Abies* and *Pinus sylvestris* is also true for *Betula pubescens* and *Picea Abies* and, furthermore, for *Betula verrucosa* and *B. pubescens*. In all of these cases, the flowering times are as close to one another as is possible without the overlapping portions exceeding 10 %. It is obvious that a more extensive overlapping would interfere seriously with the flowering physiology of those species flowering later (cf. Sarvas 1970a, p. 15).

The spring time favourable in many respects from the point of view of flowering is short and evolution seems to have divided it as efficiently as possible between the most important local anemophilous tree species.

Comparisons with Conditions in Nature

Most of the available material suitable for comparison pertains to the progress in nature and under experimental conditions of the microsporogenesis in *Larix sibirica*, *L. decidua* and *L. Gmelini*. Here, the comparison is confined to the p.u. sum covering the time lapse between MI and MII.

Under the experimental conditions involved, the p.u. sum covering the time lapse between MI and MII in the microspore mother cells of *Larix sibirica* was determined on the basis of 2 separate series of experiments. In the former series, the result obtained was 112.9 ± 6.4 p.u. and in the latter, 112.2 ± 3.72 p.u. Correspondingly, for *L. Gmelini*, the p.u. sum measured from MI to MII was 106.0 ± 5.36 p.u.

In nature, the observation of microsporogenesis consisted in the fixing of male buds at short (0.5—1 day) intervals. Each fixing comprised about 25 buds. The investigation was carried out at individual as well as at population level. The buds were examined by using the pooled squash method. The squash comprised 5 anthers from each bud.

The temperature was measured with thermocouples, the points of which had been pushed into the buds. The temperature of 4 buds selected from

Table 10. Results of measurements in nature of p.u.-sums of the cycle interval MI → MII in microsporogenesis of some *Larix* species

Locality	Sample plot: tree No.	Year	MI → MII in nature	
			Buds	Screen
			p.u.	
	Larix sibirica			
Punkaharju	8:14	1969		85
»	8:14	1970	101	66
»	8:4	1970	91	68
»	49:	1971	111	72
Rovaniemi	26:62	1970		69
»	26:66	1970		70
	Larix decidua			
Punkaharju	27:6	1969		83
»	27:7	1969		90
»	27:6	1970	105	65
»	27:7	1970	108	65
	Larix Gmelini			
Punkaharju		1970	102	87

the different sides of the tree were recorded by a multipoint recorder. Subsequently, the mean value was calculated for the recorded temperatures. The calculation of the p.u. sums pertaining to the buds is based on these mean values. Table 10 shows the results of measurements made in 1970—1971.

Let us first give attention only to the p.u. sums pertaining to the buds. It can be seen that the results referring to years 1970 and 1971 differ from one another only slightly. The p.u. sum covering the time lapse between MI and MII is for *Larix sibirica* approximately 101 p.u. and for *L. decidua*, 107 p.u. For *Larix sibirica* the p.u. sum covering the time lapse between MI and MII has risen under controlled temperature conditions to about 112. For *Larix Gmelini* the p.u. sum measured from MI to MII was in nature 102 p.u. and under experimental conditions 106 p.u. For instance, in terms of percentage, the differences are considerable, but when all the imperfections inherent in the measuring technique are taken into consideration they can hardly be regarded as significant.

Comparison can also be made between measurements carried out in nature under varying temperature conditions regarding the receptive p.u. interval in the female cones of *Picea Abies* and corresponding measurements performed in an incubator at a constant temperature. The experiment referred to was conducted at Punkaharju in the spring of 1969. Measurements were made twice a day on 15 randomized trees in sample stand LII. They were begun in good time before the onset of flowering and were not finished until the female cones had turned from flower position to cone position. When the investigation was begun, 15 female cones were chosen at random from each tree, and observation was concentrated on them. At each observation time, the number of the female cones that had opened (+) and the number of those that had not (—) were recorded. Later on, the number of the female cones that had closed again (++) and of those that had not (+) were recorded. In this way, the cumulative frequencies for the p.u. sums of the opening and closing phenomena were obtained. With the aid of the frequency scale, it was then possible to calculate very accurately the p.u. interval between the opening (50 %) and closing (50 %) (receptive p.u. sum).

When the investigation was undertaken, branches 0.5 meter long and having female cones were taken from the same randomized trees. The female cones originating from each tree numbered 20. The cones were forced in an incubator at a temperature of 17°C and the observations made were identical with those recorded in nature.

The p.u.sum obtained with respect to the receptive interval in the incubator was 1 480 $\pm$ 0.187 p.u. and the corresponding figure arrived at in nature was 1 520 p.u.

It is obvious that a larger and more comprehensive number of comparisons will be required before it is possible to determine to what extent the reactions recorded in incubators in the course of this study can be applied in the interpretation of phenomena which take place in nature. It will take a considerable amount of work to clarify this point.

The fact that experimental results obtained under laboratory conditions were applied successfully to the observations made in nature supports, at least to some extent, the opinion that the progress of the active period in nature is controlled primarily by temperature and time. How is this to be understood? Even though some light has been thrown on this question above it remains largely open.

The progress of the active period is the outcome of a sequence of physiological phenomena which occur primarily in the apical and lateral meristems of a tree. It seems reasonable to speculate that these meristems are well protected against the effects of environmental fluctuations other than those occurring in temperature and in the atmospheric humidity. This has a particular bearing on the water content of meristems. However, it is possible that it takes an exceptionally long period of drought to bring about a decrease in the water content of meristems. Later investigations will have to clarify the effect that drought has on the progress of the active period.

Screen and Bud Temperatures

The results given in Table 10 provide interesting and illustrative information concerning the technique of temperature measurement. In addition to being measured by means of thermocouples inserted into buds, the temperature was also recorded by means of a thermograph and control thermometer placed in a meteorological screen above the crown canopy. From Table 10 it can immediately be seen that the p.u. sums based on the measurement of bud temperatures are larger than those based on the conventional measurement of air temperature.

This establishment immediately raises the question as to whether or not the p.u. sums based on air temperature are on the whole serviceable when the aim of study is to clarify which environmental factors have an effect on the progress of the active period in nature.

In this case, as in many other cases concerning similar questions of measurement technique, it should probably first be established that much depends on for what purpose the services provided by p.u. sums are intended. It should be noted that also the temperature readings obtained from the bud by means of thermocouples are only approximate values. One of the difficulties contributing to this is that in the spring, after flushing, there

follows a 1- to 2-month period when there are no buds or they are so poorly developed that the measurement of temperature within them is very hard.

Furthermore, it is to be noted that the differences between the temperature readings obtained from within the bud and those recorded in the meteorological screen are largest in the spring, to which period the information contained in Table 10 pertains. It is important to get a more complete picture of the differences between the p.u. sums of the buds and those of the air in the different parts of the year. It should, however, be taken into consideration that the differences between the bud p.u. sums and the screen p.u. sums shown in Table 10 are not entirely due to the differences existing between the temperature within the buds and in the air. Another contributing factor is that the meteorological screens were located above the crown canopy and the buds involved, within it. The differences resulting from this are shown in Table 11.

Table 11. Comparison between p.u. sums based on temperatures measured in screens located at canopy level (B) and above canopies (A). *Pinus sylvestris*, Heinola 566. Dominant height of the stand 1961 22.3 m.; A-screen 21.4 m. and B-screen 16.9 m. above ground level

Date	Year of temperature measurement									
	1965	1966	1967	1968	1969	1965	1966	1967	1968	1969
	Cumulative p.u. sums					P.u. sums of decades				
	100 A/B									
1. 3.				96					98	
11. 3.		86		97					98	
21. 3.		100	103	98	107		102		100	
31. 3.		99	100	101	104		98	98	102	103
10. 4.	98	100	100	101	103		100	100	103	102
20. 4.	98	99	99	99	102	98	93	103	95	100
30. 4.	98	98	102	103	101	97	96	103	110	100
10. 5.	97	98	102	102	101	95	99	102	100	100
20. 5.	97	98	102	102	101	95	97	101	99	103
30. 5.	97	98	102	101	101	97	100	102	100	100
9. 6.	97	99	102	101	100	98	99	101	100	98
19. 6.	97	98	102	101	101	98	99	101	100	102
29. 6.	98	99	101	100	101	98	100	100	99	101
9. 7.	97	99	101	100	101	94	99	102	100	99
19. 7.	97	98	101	100	100	98	89	101	99	99
29. 7.	97	99	101	100	100	98	108	101	99	100
8. 8.	97		101	100	100	98		101	99	98
18. 8.	97		101	100	100	99		99	100	101
28. 8.	98		101	100	100	90		103	102	101
7. 9.	98			100	100	97			102	101
17. 9.	98			100	100	98			100	103
27. 9.	98			100	100	98			100	101
7. 10.				100	100				102	100
17. 10.				100	100				101	101
27. 10.				100	100				102	99
6. 11.				100	100				100	107
16. 11.				100	100				100	98
21. 11.				100	100				90	98
6. 12.					100					93
16. 12.					100					95

Table 11 indicates that in a *Pinus sylvestris* stand there are differences between the p.u. sums measured at crown level and those measured above the crown canopy. The differences are, however, fairly small, about 3—5 %. Measurements were also performed in a *Picea Abies* stand, Bromarv I, in years 1965—69 and the results were similar.

Comparative clarifications of the meteorological screen p.u. sums and the bud p.u. sums were made, in particular, in a *Pinus sylvestris* stand at Punkaharju especially well suited for this purpose, in 1970 and 1971. Readings of the temperature within the bud were taken from 4 randomized male buds located on different sides of the crown. The results are compiled in Table 12 and comprise two groups: measurements made in spring and measurements made in the latter part of the summer.

The differences between the screen and the bud p.u. sums reach their peak in the spring as can be expected. Particularly, on bright days early in the spring, the buds hit by the sun become warm quickly even though the temperature of the air might be below zero. The largest difference was recorded at 11 o'clock on March 26, 1970 when the temperature in the screen was —2.3°C and in the bud, 17.7°C. However, differences of this magnitude are exceptional and of short duration. In the series of measurements made in the spring of 1970, the screen p.u. sums average about 77 % of the bud p.u. sums and in the spring of 1971, 86 %.

The differences between the screen p.u. sums and the bud p.u. sums were much smaller in the autumn than in the spring. In the autumn of 1970, the screen p.u. sums averaged about 93 % of the bud p.u. sums.

One important detail yet merits attention. Table 10 shows results of measurements made in the Rovaniemi rural commune in northern Finland concerning the microsporogenesis of *Larix sibirica*. In the screen p.u. sum, the cycle interval MI→MII was in 1970 almost the same as in Punkaharju in the year involved. The fact that the day is much longer in northern Finland at the time *Larix sibirica* flowers, does not seem to have any appreciable effect on the ratio between the screen and the bud p.u. sums. However, additional material is, of course, needed to clarify this question.

It has, of course, from the outset been obvious that there are differences between the screen and the bud p.u. sums. It is important to have some knowledge of their magnitude but it may be even more important to know the extent to which these differences vary in different years. From what has been said above, it can be concluded that in sunny springs particularly and also in sunny summers the differences may be larger than in cloudy springs and cloudy summers. The information published by weather stations concerning the number of hours of sunshine provides an opportunity for at least a rough estimation of the magnitude of the differences. Here, too, it is well to repeat that for certain purposes, a satisfactory estimation of the

Table 12. Comparison of p.u. sums based on temperatures measured in screens and buds, *Pinus sylvestris*, Punkaharju XLVI, 1970 and 1971. Sums of sunshine-hrs were 1970 reckoned at Ruokolahti, 60 km. South-West of Punkaharju and in 1971 at Lappeenranta, 80 km. South-West of Punkaharju

Days	Cumulative		Scr./Bud	Decade		Scr./Bud	Sunshine
	Screen	Bud		Screen	Bud		
	p.u.		%	p.u.		%	hrs.
			1970				
22. 3.—31. 3.	56	107	52.3	56	107	52.3	46.3
1. 4.—10. 4.	246	404	60.9	190	297	64.0	35.8
11. 4.—20. 4.	405	618	65.5	159	214	74.3	30.8
21. 4.—30. 4.	663	926	71.6	258	308	83.8	16.1
1. 5.—10. 5.	1 697	2 275	74.6	1 034	1 349	76.6	100.0
11. 5.—20. 5.	2 575	3 403	75.7	878	1 128	77.8	101.9
21. 5.—30. 5.	3 838	5 007	76.7	1 263	1 604	78.7	93.9
9. 8.—18. 8.	2 273	2 430	93.5	2 273	2 430	93.5	65.6
19. 8.—28. 8.	4 440	4 821	92.1	2 167	2 391	90.6	76.0
29. 8.— 7. 9.	6 367	6 939	91.8	1 927	2 118	91.0	60.4
8. 9.—17. 9.	7 804	8 418	92.7	1 437	1 479	97.2	20.1
18. 9.—27. 9.	8 699	9 348	93.1	895	930	96.2	27.3
28. 9.— 7. 10.	9 168	9 867	92.9	469	519	90.4	20.0
8. 10.—17. 10.	9 686	10 419	93.0	518	552	93.8	27.7
18. 10.—27. 10.	10 055	10 773	93.3	369	354	104.2	6.0
			1971				
3. 3.—12. 3.	7	9	77.8				53.1
13. 3.—22. 3.	89	91	97.8	82	82	100.0	26.6
23. 3.— 1. 4.	228	261	87.4	139	170	81.8	32.6
2. 4.—11. 4.	491	565	86.9	263	304	86.5	69.1
12. 4.—21. 4.	737	853	86.4	246	288	85.4	80.7
21. 4.—30. 4.	813	1 022	79.5	96	191	50.3	99.1
1. 5.—10. 5.	1 778	2 288	77.7	965	1 266	76.2	115.6
11. 5.—20. 5.	3 136	3 841	81.6	1 358	1 553	87.4	107.4
21. 5.—30. 5.	4 054	5 114	79.3	918	1 273	72.1	65.8
19. 8.—28. 8.	2 267	2 515	90.1	2 267	2 515	90.1	88.3
29. 8.— 7. 9.	3 847	4 199	91.6	1 580	1 684	93.8	55.3
8. 9.—17. 9.	4 798	5 260	91.2	951	1 061	89.6	66.0
18. 9.—27. 9.	5 827	6 345	91.8	1 029	1 085	94.8	29.6
28. 9.— 7. 10.	6 342	6 874	92.3	515	529	97.4	41.1
8. 10.—17. 10.	6 697	7 239	92.5	355	365	97.3	50.8

p.u. sums of the buds seems to be possible by means of the p.u. sums measured in the screen and that for certain other purposes this does not appear possible. For instance, when investigating how the release of dormancy II (S a r v a s 1970b) and the onset of the active period depend on temperature conditions, it is obviously beneficial and perhaps necessary to resort to bud temperatures.

Neither of these p.u. sums is superior to the other. Each of them has its advantages and disadvantages. Apparently it is wise to employ both of them simultaneously whereby they will complement each other. Screen p.u.

sums have that great advantage that in calculating them one can take advantage of the temperature readings taken by weather stations and published by meteorological institutes. These measurements cover a wide range as regards both time and space. Although the screen temperatures and the p.u. sums based on them have some disadvantages, it is in many cases far better to employ them rather than to ignore the thermal factor and especially the combined effect of time and temperature or estimate it by a seemingly more accurate parameter that might turn out to be even more clumsy.

Discussion of some Heat Sum Methods

It is evident from the foregoing that by experimentation it is possible to determine fairly accurately the regression of the rate of progress of the active period on temperature. This makes it possible to view principles and methods previously employed in the calculation of heat sums from a new angle.

It is a generally known fact that the rate of speed of many natural phenomena depend, to a remarkable extent, on temperature. A closer scrutiny of the matter reveals, however, that in most cases it is not a question of temperature alone, but of temperature and of time. Hence, generally speaking, it may be said that the term heat sum refers to a parameter which by one cardinal number seeks to imply the joint effect of temperature and time on a given physical or biological (physiological) phenomenon. Furthermore, it is characteristic of most of the heat sum calculation methods that only temperatures exceeding a given threshold value are regarded as effective and, therefore, it is only they that are taken into consideration.

This idea was probably introduced by Burckhardt (1860) and a few years later, de Candolle (1865) promoted it. They both emphasized that as far as plants are concerned, the decisive threshold is obviously at a temperature higher than zero. In forestry, the most widely applied threshold values are 0°C (e.g. in the Soviet Union and Norway), 3°C (e.g. in Sweden), 5°C (e.g. in Finland), and 6°C (e.g. in Norway).

The application of the heat sum idea itself is almost as ancient as the accurate measurement of temperature. De Reamur (1735) employed the sum of the April—June daily mean temperatures to demonstrate that the agricultural crop matured earlier in 1734 than in 1735, because the heat sum was higher in the summer of 1734. Subsequently, the improvement of the various heat sum methods has become an important part of the phenological research being carried on. Concerning phenological research as a whole as well as the historical development of the heat sum methods, Schnelle (1955) has published an excellent summary of work to which reference is made in this connection. From this work it is evident that the research done in this field is impressive, if not formidable (cf. also Weger

et al. 1940, s. 1: »Es ist ja kein Grund vorhanden, vor der Fülle der Einzelfaktoren die Waffen zu strecken»). The investigations on heat sum methods published by Burckhardt (1860), Linsser (1867), Oettingen (1882), Weger et al. (1940), and Arzt and Ludwig (1949) are, amongst others, of great significance.

However, much unnecessary confusion and seeming contradiction has apparently risen from the fact that the group of phenomena in the causal interpretation of which the heat sum method has been resorted to has never been clearly defined. This is particularly true in the case of the active period and growth, between which a clear line of distinction has not been drawn.

It should, perhaps, be initially established that the concept of some kind of pure meteorological heat sum can hardly ever be quite clear, especially if the heat sum is intended to serve the causal interpretation of phenomena in the organic world. Each biological phenomenon depends in its own way on the heat factor and on time. In the calculation of the heat sum, the dependence on temperature specific to the study object and the phenomenon concerned should invariably be clarified and taken into consideration, if the heat sum is to prove really serviceable in mapping out the phenomenon involved or in a deeper understanding of it.

Let us start the inspection of heat sum calculation methods by employing a degree hour (d.h.) principle that has for its threshold value 5°C. This principle can be expressed by the following equation:

$$T_{5°C} = \sum_{i=1}^{n} (t_i - 5) \tag{7}$$

in which $T_{5°C}$ is the heat sum whose threshold value is 5°C, n the number of those hours, the mean temperature of which is higher than 5° and t_i implies the mean temperature of the ith hour. Briefly stated, the d.h. principle refers to a heat sum that is obtained by adding up those portions of the hourly mean temperatures that exceed 5°C in the period under observation.

This means that at a temperature of 5°C, the addition to the heat sum is zero, regardless of the length of the period of time involved; at a temperature of 6°C, the passage of one hour increases the heat sum by 1 d.h., at a temperature of 7°C, by 2 d.h., at 8°C by 3 d.h. In Fig. 20a this is illustrated graphically. On the horizontal axis, the constant temperatures are marked and on the vertical axis, the amount by which the heat sum increases hourly in constant temperatures.

A d.h. principle in which a 5°C threshold value is applied can thus be illustrated graphically by a straight line that intersects the x-axis at 5°C and passes through the unit point (x = 6°C and y = 1 d.h./h.). Actually, this

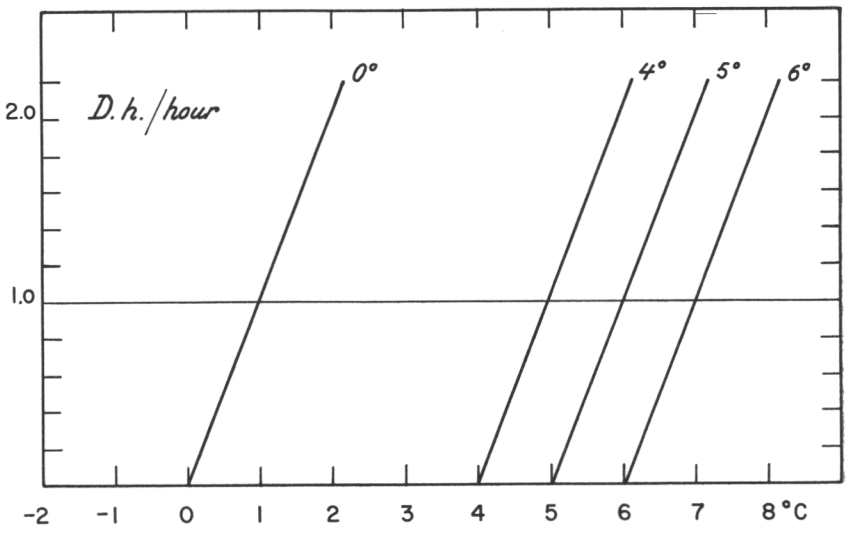

Fig. 20a. Graphic illustration of the different threshold value principles (0°, 4°, 5°, and 6°C) of the degree hour temperature sums. The horizontal axis shows the temperature scale of the constant temperatures, and the vertical axis the rate of progress of the active period. Each threshold value principle has its own unit for the rate of progress, the 0° — principle has the largest and the 6° — principle, the smallest.

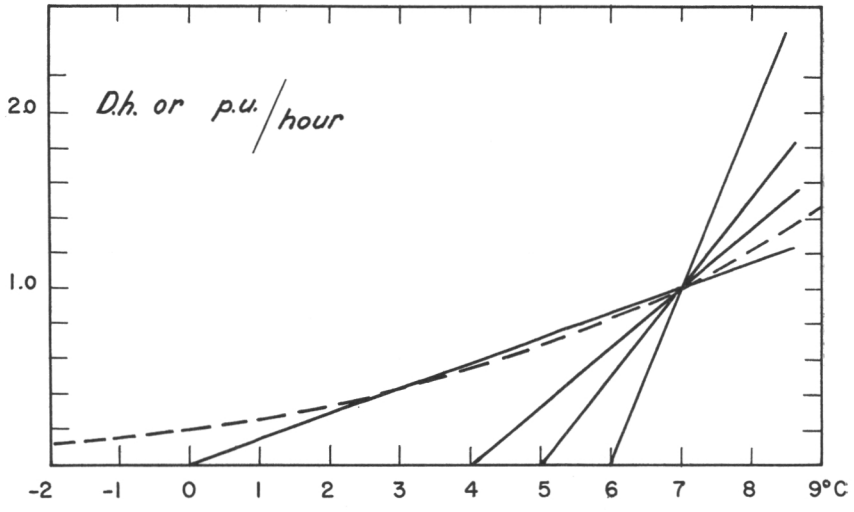

Fig. 20b. Graphic illustration of the different threshold value principles (0°, 4°, 5°, and 6°C) of the degree hour temperature sums. The horizontal axis shows the temperature scale of the constant temperatures, and the vertical axis the rate of progress of the active period. All the threshold value principles have a common unit for the rate of progress. In addition, a plotted line demonstrates the regression of the experimentally determined rate of progress of the active period (p.u./hour) on temperature.

statement can be extended to apply to all the threshold values: those heat sums in the calculation of which the d.h. principle is employed can be illustrated by straight lines that intersect the x-axis at the threshold value and pass through the unit point (x = threshold value plus 1°, y = 1 d.h./h.). When one wishes to compare different threshold values, it is appropriate to draw the straight lines on the same scale, i.e. to give them the same unit point (Fig. 20b). The abscissa value of the unit point must, of course, be higher than any of the threshold values to be compared with one another. In this case, too, all the straight lines to be compared with one another pass, of course, through the unit point and, in addition, each of them intersects the x-axis at the point of their own threshold value. The straight lines to be compared are thus easy to draw on any scale.

The question arises as to which threshold value best approximates the progress of the active period. We immediately realize that the answer essentially depends on the temperature range within which the phenomenon under observation occurs. If the temperature range involved is narrow and does not extend far from 18°C, and we wish to approximate the regression of the rate of progress of the active period on temperature with one straight line, the inflectional tangent of the curve that illustrates the true regression

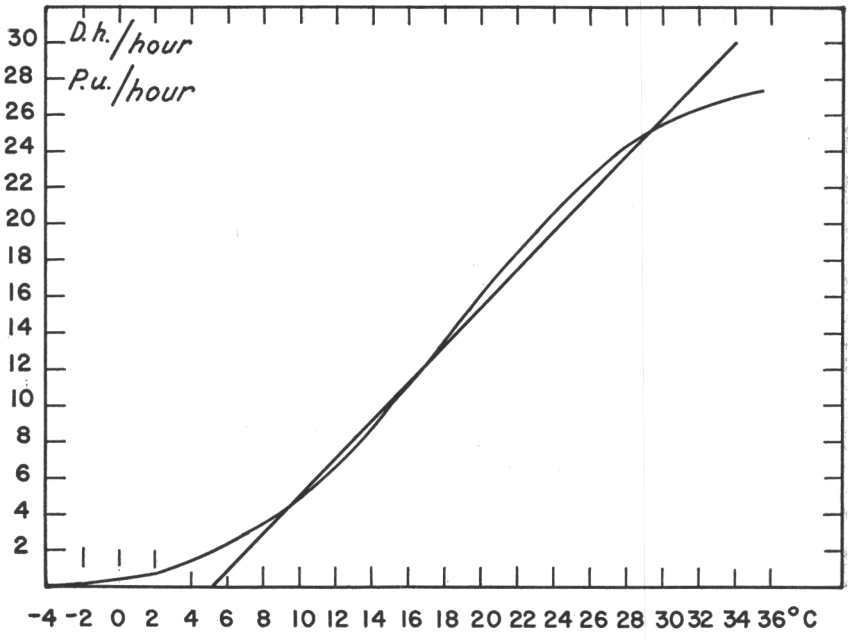

Fig. 21. Graphic comparison between temperature sums calculated by employing the d.h. principle with a threshold value of 5°C and the rate of progress of the active period determined under experimental conditions.

is, without doubt, the best approximation. From Fig. 21 it can be established that the threshold value of the d.h. principle that corresponds to the tanget drawn to the point of inflection is about 6.8°C. Often, however, the phenomenon under observation occurs within an essentially wider temperature range. For instance, in southern Finland the progress of the active period of forest trees mainly occurs in temperatures between 10° and 27°C. A temperature range of this kind is well approximated by a threshold value of 5°C. Fig. 21 shows that in consideration of this temperature range, a 5.5°C threshold value would evidently be even better. It is interesting to note that the same conclusion has been reached earlier on the basis of information that in principle is very different (Sarvas 1967, pp. 217—218). Also, it is surprising to note how well, in practice, the situation has been estimated in the Northern countries merely on the basis of a thumb rule of some kind: as has been mentioned already, in Norway the threshold value in common use is 6°, and in Finland, 5°C (e.g. Kolkki 1966, p. 23 and 42).

Where the essential portion of progress of the active period occurs at lower temperatures ranging, for instance, between 5° and 20°C, a threshold value of 4°C approximates the situation better. When a heat sum is intended for use within the 0° and 5°C limits, a threshold value of 0° is good, and so forth. Thus, there is no threshold value clearly superior to the others and, therefore, the choice must depend on the nature of the task involved. In this connection it should perhaps also be pointed out that any effort to approximate with a straight line the regression of the progress of the active period on temperature inevitably leads to speculation about the threshold value and the shortcomings that attend upon it.

It is evident that the good services the d.h. and d.d. principles (with 5°C threshold value) have performed earlier (cf. e.g. Sarvas 1967, p. 217) are due to the fact that, with some luck, the d.h. and d.d. principles, in the choice of which a thumb rule of some kind is employed, approximate the true situation rather satisfactorily.

On the other hand, it can be seen that when conventional threshold values, such as 4°, 5° or 6°C are employed under low temperature conditions, the rate of progress of the active period is approximated incorrectly. The error thus incurred is of no great importance in the middle (midsummer) of the active period, because the absolute contribution made by the low temperatures to the progress is very slight as compared with the great contribution made by the high temperatures. The situation is different at the early phases of the active period (early summer) when the progress of the active period, as a rule, occurs almost exclusively at low temperatures. Owing to this fact, when employed in the observation of the early phases of the active period, the d.h. and d.d. principles based on any of the above mentioned threshold values are completely misleading. This was one of

the reasons which, in the investigation of these phenomena, forced us to abandon the d.h. and d.d. principles and to delve deeper into the question of how, more exactly, the rate of progress of the active period depends on temperature.

All things considered, it is evident, and important to note, that in view of the whole temperature range in nature, the dependence of the rate of progress of the active period on temperature cannot be approximated satisfactorily with one straight line.

Despite their deficiencies and limitations, the d.h. and d.d. principles, particularly the latter afford us one great advantage: when based on them, the calculation of heat sums is very simple and easy. For this reason, these principles can without doubt continue to be used for many purposes of a practical nature. Now that we can clearly perceive what kind of errors are made in their application, it is easier than before to determine the purpose for which they can, and cannot, be successfully used. Earlier investigations (S a r v a s 1967, p. 217) have revealed that between the d.h. and d.d. principles there is no appreciable difference in the accuracy with which, by employing either of them, it is possible to simulate the progress of the active period. The d.h. principle, as far as the manipulations involved are concerned, is in a way more correct than the d.d. principle, but the calculation of the d.d. heat sums is much easier than that of the d.h. heat sums; so, if the p.u. method is abandoned for the purpose of simplifying the calculations, the application of the d.d. principle (with a threshold value of 5°C) may be recommended.

In addition to the d.h. and d.d. heat sum principles referred to above, the so-called M o r k's heat sum has been widely used, particularly in the Northern countries. M o r k (1941, pp. 72—73) defines the unit of his heat sum as follows: »En vekstenhet vil jeg derfor definiere som den varmeeffekt som en får når middeltemperaturen for de 6 varmeste timer om dagen er 8°C» (in the German-language summary, p. 85: »Eine Wuchseinheit definiere ich deshalb als den Wärmeeffekt, den man bei einer Mitteltemperatur von 8°C für die 6 wärmsten Stunden des Tages erhält»).

In Hirkjølen Experimental forest, M o r k (1941) investigated the dependence of the height growth of Picea Abies on temperature. He divided the time during which the height growth occurs into three periods: 1st growth phase, in which height growth occurs at an increasing rate even under constant temperature conditions, 2nd growth phase, in which the rate of height growth under constant temperature conditions is almost invariable, and 3rd growth phase, in which the rate of height growth, even under constant temperature conditions, declines. In his research, M o r k concentrated the investigations on the middle phase of the seasonal growth. In this way, he consciously eliminated as far as is generally possible, the influence of the progress of the active period on the phenomenon under investigation. Since it was the dependence of height growth on temperature that M o r k wished to clarify, he proceeded very skillfully. As quoted above, he refers to the unit of his system as the growth unit. The concepts created by M o r k and the investigatory method developed by him have had, in spite of their being concerned with growth and not with the develop-

mental cycle, a profitable influence on the present investigation; or, rather, perhaps the influence is due to the very fact that the research was concerned with growth rather than with the active period. In this connection reference may be made to the analogy between the definition of M o r k's growth unit and that of the unit of cycle interval applied in this study.

It would perhaps also be well to comment briefly on the method of describing thermal conditions (length of the growing season) by stating the number of (effective) days (i.e. the number of those days that are effective from the point of view of plant development, abbr. eff.d.), the mean temperature of which exceeds a given threshold value, e.g. 5° or 6°C.

This method is based on a threshold value idea similar to that employed, for instance, in the degree day (d.d.) and degree hour (d.h.) methods. Thus, what above has been said of threshold values also applies to the method under discussion.

It is obvious that when the average annual eff.d. sum (for instance, as a mean of 30 years) and, for instance, the average annual d.d. sum, are calculated for different localities there is generally a high positive correlation between these parameters. In climates of the same type (a sea climate or a continental climate) the degree of this correlation may be so high that it is almost of no consequence which parameter is used. But when the localities to be described comprise maritime as well as inland areas, the eff.d. sum gives, per annum, relatively less emphasis to the very warm days than does the d.d.sum. Whether or not this is what is desired depends, of course, on what the study involved is concerned with. However, when the thermal conditions of single years are described it seems obvious that the annual d.d. sum is more serviceable than the annual eff.d. sum.

As has been pointed out above, each biological phenomenon depends, in its own specific way, on temperature and time. Therefore, each phenomenon or, at least, each group of phenomena, should be investigated separately; it is not likely that there is in existence any general formula specifying the dependence of various biological phenomena on temperature and on time. In the present study, light has been thrown on the dependence of the rate of progress of the active period on temperature. The regression obtained is not serviceable in solving problems concerning growth, for instance. This is demonstrated by the fact that the active period progresses undisturbed in almost complete darkness even for weeks, whereas the growth of green plants is most essentially, indirectly or directly, dependent on the radiation energy of light. In solving problems directly or indirectly concerned with growth, M o r k ' s heat sum evidently renders good services.

Physiological Clock

In biological research taken as a whole and particularly in investigations concerning arborescent plants, such as fruit trees and forest trees, heat sums calculated on the basis of different principles have been resorted to with some success. The fact that this is so implies that parameters of the kind involved have a certain scientific and practical value.

In the present study, the regression of the rate of progress of the active period on temperature has been determined experimentally. This regression affords an opportunity to illustrate accurately how the rate of progress of the active period depends on temperature. The extent of the progress that the active period has made between times t_1 and t_2 under varying temperature conditions T (t) is expressed in a general form by equation (2) on page 13. The unit of cycle interval in the active period has been termed the period unit (p.u.). The sum arrived at by applying equation (2) is, accordingly, termed the period unit sum (p.u. sum). In practice, however, the calculations are carried out by applying equations (3) or (4), which approximate equation (2) with the accuracy desired in each particular case.

At first, it may seem that a p.u. sum formed in this manner is no more than a heat sum calculated more accurately than before. This, however, is true only to a certain point. Particularly, with regard to the degree day and degree hour heat sums examined above, it must be said that they are so-called degree sums which, by applying a certain kind of thumb rule, approximate the regression of the rate of progress of the active period on temperature as linear and, in addition, employ the threshold value idea that is, at least, to some degree foreign to biological thinking.

In respect of the period unit sum arrived at in the present study, no values have been approximated by the rule of thumb but rather the regression of the rate of progress of the active period on temperature has been determined by means of experiments conducted under controlled environmental conditions and there has been no need for a threshold value presumptive view. Thus, the problem concerning the principle of the physiological clock has also been solved. It is in accordance with this clock that the progress of the active period occurs, and in a given geographical area the

clock times the active periods of trees of a whole population and even the active periods of populations of several different tree species, so that during the entire growing season they are well synchronized.

Furthermore, since this innate physiological clock depends on only two factors, time and temperature, the measurement of which, with conventional physical equipment, is relatively simple and accurate, it is easy by means of mere physical measurements to simulate the running of the innate physiological clock of the trees. This is, in fact, the true essence, purpose and goal of the calculation of the period unit sums.

The calculation of the p.u. sum presupposes an accurate knowledge of time and temperature. The measurement of time does not, as a rule, run into difficulties. There are even very accurate instruments for this purpose in use. But, as regards temperature, its measurement with adequate accuracy generally involves considerable difficulties. To begin with, it should be established that, as a rule, it is often necessary to resort to measuring the temperature of the air which is, of course, hardly ever exactly the same as that of the object under research [1]). In forests, the temperature of the air varies very much at the horizontal level as well as in a vertical direction and, therefore, it has often been considered appropriate to carry out climatical measurements aimed to serve physiological forest phenomena, in a nearby open area, at the traditional height of 2 m. or higher. A second alternative is to perform the measurements above the crown canopy. It is this latter method that has been used in the present study. At this level, the horizontal variation is, without doubt, even smaller than at a height of 2 m. in an open area and, therefore, it is hoped that the situation can be handled satisfactorily by means of a single measurement point. Taking temperature readings above the crown canopy has also seemed appropriate on account of the fact that in trees growing in closed stands, the majority of the male and female flowers are located at the tops of the crowns, and because it is in their development that several good point events of the active period are easy to find.

For the measurement of temperature, masts reaching to the dominant height of trees or higher, and fitted out with ordinary Stevensen's screens with equipment have been erected in the experimental stands. The equipment used consists of a thermograph and a control thermometer. The checking is done twice a day. An arrangement of this kind has the great advantage that measurements can be carried out at a reasonable cost in several widely

1) In the experiments dealt with above and which were carried out at controlled temperatures to determine the dependence of the rate of progress of the active period on temperature, the experimental technique was, in fact, such that the temperature of the research object was almost the same as that of the air whose temperature was measured. Because of the high relative humidity prevailing during the tests, the transpiration from the surface of the research object and the drop in the temperature it caused were slight.

separated stands and often far away from electricity. It is often difficult to find a good experimental stand in a location where recording thermocouples or thermistors can be used.

The inspection of the progress of the active period is of interest at the individual (i.e. one genotype) as well as the population level. In the former case, the genotypic variation is eliminated whereas in the latter, it is more or less pronounced.

When inspection is confined to an individual tree, it could, perhaps, at first be assumed that in the progress of the active period, the variation between the different parts of a tree is fairly slight. However, this is not the case. To begin with, it should be noted that the p.u. sum varies in the different parts of a tree, as, for instance, the south and north side of the crown, and that in some years the degree of variation is considerable. Of even greater significance is the topophysis variation in a tree: for instance, the dwarf shoots react to the thermal factor differently from the long shoots and so forth. In the following, the variation within a single individual tree, as the antithesis of genotypic variation, is referred to (c.f. Falconer 1964, p. 112: »the environment is all the non-genetic circumstances that influence the phenotypic value») as environmental variation. Although the variation within an individual tree observable in the progress of the active period gives an idea of the magnitude of the environmental variation, it should be noted that the variation in question is only a small portion of the total environmental variation of the population and even of the subpopulation to which the individual tree belongs. This is clearly exhibited, for instance, by *Populus tremula* clone stands where the environmental variation of the whole subpopulation is considerably greater than that of any individual tree. This also applies to clone banks (and seed orchards) because, between the different ramets of a clone, there might be considerable and, at first sight, surprising differences in the progress of the active period due to the great environmental variation specific to this phenomenon.

Because of the great environmental variation, the sampling and investigation of but a few point events of the active period of a single individual tree is no minor task; as a matter of fact, the amount of work required is not appreciably less than that involved in investigation at the population level and, what is more, it may be more difficult in many respects. One of the difficulties encountered at the individual level, particularly in the investigation of point events involving microscopy, is that the investigator easily runs out of male and female flowers and other research material, since each microscopy requires a fresh specimen.

Mapping out of the Active Period

Now that the principle on which the innate physiological clocks of the trees under investigation operate in controlling [1]) the rate of progress of the active period has been clarified and it has been demonstrated that it is possible to simulate this clock by means of a period unit sum based on purely physical measurements, the question arises as to what immediate services this clock can offer us in the mapping out of the sequence of events in the active period.

To begin with, it must be established that, at least for the time being, we are unable to observe without interruption the progress of the active period, i.e. from point to point, as we can observe e.g. the height and diameter growth of a tree. This may be one of the reasons why in the studies into the progress of the active period, growth has often been resorted to. Growth can be measured continuously and, therefore, also continuously observed. However, as has been emphasized in the foregoing, the progress of the active period and growth are phenomena so different that the observation of growth can hardly provide serviceable information on the progress of the active period.

Although continuous observation of the progress of the active period seems to encounter unsurmountable obstacles, it is, however, possible, as has been seen in the foregoing, to find in it physiological events, i.e. such point events that are more or less easy to observe and are serviceable in the mapping out of the active period. In the present study, point events of this kind have been termed cardinal phases. This is, of course, exclusively a working term; in principle, cardinal phases do not differ essentially from numerous other, less conspicuous, developmental events taking place between the cardinal phases.

Point events of this kind are found in the developmental processes of the vegetative as well as the generative organs of trees. The vegetative

[1]) We do not know anything about the biochemistry of this control and, as a matter of fact, when we term this phenomenon »control« we do so to conceal our ignorance; it is very possible that no control exists but that the trees conform to their innate physiological clocks for the simple reason that the rate of speed of those biochemical processes that comprise the active period depend on time and temperature in accordance with the regression shown on page 31.

physiological events, such as flushing and leaf abscission, generally have a very important advantage over the generative events, namely that in them, the whole tree or population participates, whereas, in many a year, only a portion of a tree or population, and what is more, a biased portion, is generatively active.

Therefore, it would seem appropriate to resort primarily to the observation of vegetative organs, leaf buds, leaves, and the function of the cambium. Particularly, flushing and leaf abscission appear to be point events of the kind that lend themselves to accurate observation.

In the observation of the vegetative organs, the greatest difficulty at the present moment is that not many good and serviceable point events, whose sampling and investigation do not involve too much work, have so far been available. Actually, the only suitable events have been the above-mentioned flushing and leaf abscission. Studies conducted by Langlet (1936), Dietrichson (1964) and Hagner (1970b) indicate, however, that there are other possibilities.

In his last-mentioned publication, in particular, Hagner (1970b, pp. 15—20) describes the following methods and critically compares them with one another: 1. measurement of shoot elongation in June, 2. measurement of needle length during shoot elongation between June and July, 3. determination of colour of the bark on the terminal shoot in August, 4. determination of dry matter content in needles in October, 5. determination of the degree of lignification in the periphery of the stem wood between August and October, 6. determination of electric conduction resistance in the stem's outer portions, phloem, cambium and xylem in the September—October period and 7. determination of bud set between July and August. In comparing the serviceabilities of the different methods with one another, Hagner lists them in the above sequence. According to his investigations, methods 1.—3. are generally the most serviceable.

In studies concerned with the active period there is, without doubt, every reason to consider seriously all the available possibilities. Methods that now seem to involve much work can certainly be simplified so as to become less laborious.

In the active period of the generative organs, it is much easier to find events that are easy to sample and investigate than it is to find them in the development of the vegetative organs. This is one of the reasons why in the present study they have frequently — perhaps too frequently — been resorted to. These point events include, for instance, the different phases of sporogenesis, dehiscence of the pollen sacs of the anthers, opening and closing of the female cones, syngamy, maturation of seed, and seed abscission. However, as mentioned in the foregoing, the fact that the whole population is rather seldom, maybe 1—3 times in 10 years, generatively

active to potential capacity, is a serious limitation. In most years, for reasons with which we are not as yet fully familiar, only a portion of the population is generatively active and, what is more, in view of the annual cycle of development, this portion is hardly random but rather a choice fraction of the population.

All the difficulties now referred to, the true magnitude of which has perhaps not always been fully appreciated, may largely be responsible for the fact that from the enormous number of phenological observations made in the world during the past 100—150 years, it has been possible to obtain only relatively few exact data of general bearing. On the other hand, these remarkable efforts manifest that the research workers in botany, particularly, have long felt strongly that the annual cycle of development of plants is a fundamental biological problem that occupies a key position in plant physiology.

Earlier, it has already been pointed out that the cycle intervals of the active period starting from the zero point (formula 4, page 14) are often of special interest. The total length of the active period, from the zero point to the end of the active period, may prove to be the most important of them. This suggestion immediately indicates that in our research, at the present moment we are still largely in a blind alley. Generally, the zero point and the end of the active period are point events that are not easily observable. However, there is at least one significant exception. In most of the *Larix* species, the active period of the pollen mother cells ends in the diplotene phase of meiosis. Consequently, the zero point of the next cycle is the diplotene phase. Furthermore, in most of the *Populus*, *Picea*, and *Abies* species, the active period appears to end in the meiotic phase immediately preceding diplotene, which would thus be the zero point of the next cycle. In this connection it should be recalled that our definition of the active period is attended by a certain degree of clumsiness: the active period begins when the winter dormancy ends, and the active period ends when the winter dormancy begins. This clumsiness would perhaps be inexcusable, if it did not bring out a certain point of fundamental importance, namely, that we can hardly ever be able to map out the active period unless we treat it as a portion of the whole annual cycle.

Recognizing this necessity, it was decided that the actual mapping out of the active period should be abandoned in this study. For instance, questions regarding the p.u. sums at which different interesting point events occur, the annual variation of these p.u. sums, and, above all, the total length of the active period of different organs of different tree species and races, must be postponed until our knowledge of the whole annual cycle is more precise. Those efforts that some research workers have made (Burckhardt 1860, Weger et al. 1940, Herbst and Weger

1940, Lessman 1948, Arzt and Ludwig 1949, Schüepp 1950, cf. also the very good summary on this subject by Schnelle 1955, p. 208) in order to solve the zero point problem, indicate that the question is not new. On the contrary, the progress of earlier studies, too, was blocked by these very same difficulties.

In view of the climatic adaptation of forest trees, the total length of the active period is of decisive importance. Regardless of what has been said above, this question, which is of great practical importance, does not pose insurmountable difficulties. Although the possibilities of determining the absolute total length of the active periods of different individual trees and whole populations are slight for the time being, it is fairly easy to determine the relative differences between various individual trees and various populations. This approach is based on the reasonable assumption that in the active periods of trees of the same species, a given cycle interval that is limited by two accurately defined physiological stages of development (i.e. by 2 cardinal events) constitutes in all the trees of this species approximately the same percentage of the total length of the active period. For instance, it is logical to assume that in respect of all individual *Pinus sylvestris* trees, the p.u. sum (the p.u. sum of the receptive stage) calculated from the time the female flowers open (50 %) till the time they close (50 %) is approximately the same percentage of the total length of the active period of the individual trees involved.

Let us review two individual trees, A and B, the p.u. sums of whose receptive stages are a_1 and b_1. The total length of the active periods of the same trees are denoted by a and b. We thus obtain

$$\frac{a_1}{a} = k \text{ and } \frac{b_1}{b} = k \text{ and from this we further obtain} \tag{8}$$

$$\frac{a}{b} = \frac{a_1}{b_1} \tag{9}$$

Thus, by applying a fairly simple technique we can determine the percentage by which the total length of the active period of A is longer or shorter than the total length of the active period of B. The information obtainable in this way is particularly serviceable in solving problems concerned with forest genetics and forest tree breeding (cf. Sarvas 1970a).

More light will be shed on the significance of the relative differences determined in this way provided the question is examined at population level. A representative sample comprising individual trees from a given *Pinus sylvestris* population is chosen, for instance, at random. The length of the receptive stage of each individual tree is determined and expressed

in period units. The length of the receptive stage of any individual tree included in the sample is denoted by n and the mean value of all the trees included in the sample, $\bar{n}$. Further, the difference $n-\bar{n}$ is calculated for each tree involved. By arranging the trees in suitably large groups according to their $n-\bar{n}$ differences, a frequency distribution illustrating the tree population concerned is obtained. The standard deviation of this frequency distribution is an important parameter. It gives the best idea of the relative magnitude of the differences between the trees. For instance, it can be agreed that individual trees deviating from the mean value less than one standard deviation may be termed normal with regard to the length of the active period in the population concerned, and that individuals deviating between 1 and 2 standard deviations may be termed »trees with a long or short active period», and those deviating more than twice the standard deviation, »trees with a particularly long or short active period». However, a considera-ation that may even be of greater importance is that by dividing the $n-\bar{n}$ differences determined for each individual tree, by the standard deviation of the frequency distribution an accurate parameter is obtained for the relative total length of the active period of each individual tree concerned. Table 13 illustrates a process of this kind.

It should, however, be recalled what has been said earlier about the relativeness of the concept of the rate of progress of the active period. Above, certain individual trees were termed »trees with a long active period» and certain others, »trees with a short active period». The basis for this grouping is that in the trees assigned to the former group, the active period is, in terms of p.u. sums, longer than in the trees belonging in the latter group.

Table 13. The relative length of the active periods of the sample trees in a sub-population of *Picea Abies*, Punkaharju sample plot No. LII, 1969. The p.u. sum at which 50 % of the female cones had passed the horizontal line was determined

Tree No.	n p.u.	$\frac{n-\bar{n}}{s}$	Tree No.	n p.u.	$\frac{n-\bar{n}}{s}$	Tree No.	n p.u.	$\frac{n-\bar{n}}{s}$
Particularly short active period								
47	5 800	—2.2	28	6 550	—0.09	14	6 750	0.5
			105	6 570	—0.03	109	6 750	0.5
			52	6 600	0.06	22	6 850	0.8
Short active period			57	6 650	0.2	103	6 850	0.8
104	5 995	—1.6	37	6 650	0.2			
49	6 070	—1.4	58	6 665	0.2	Long active period		
5	6 200	—1.1	61	6 700	0.3	10	7 100	1.5
			112	6 700	0.3			
Average active period			107	6 700	0.3	Particularly long active period		
4	6 300	—0.8	11	6 750	0.5			
16	6 300	—0.8				113	7 400	2.3
50	6 450	—0.4						
						$\bar{n}$	6 580.4	
						s	354.6	

The unit for the cycle interval of the active period, in the form it has been defined in this investigation, is not, however, generally valid. Therefore, in applying the definition concerned, each genotype is assigned an individual unit. Even though, despite this seeming chaos, we have succeeded in obtaining results of a generally valid nature, it should be remembered that the limitations attending the starting point prevail. This means that, as a matter of fact, we do not know whether the active period of any so-called long active period tree is actually longer than that of a so-called short active period tree, or whether the larger p.u. sum of the former is due to the fact that in determining it, a unit for the rate of progress of the active period was applied, which unit is smaller than the unit applied in connection with the short active period tree.

Actually, the latter alternative seems more logical, because it is reasonable to assume that the active periods of long active period trees and those of short active period trees comprise identical physiological events, but that in the former, they occur more rapidly than in the latter. Thus, to be exact, it would, perhaps, be more to the point to term these two groups of trees »rapidly developing trees» and »slowly developing trees», respectively. At least in some connections, this more precise term would seem to be expedient.

If viewed from this last-mentioned standpoint, the question of comparing the active periods of individual trees of the same species with one another will be simplified: it is necessary to compare only the rates of progress. It is reasonable to assume that in all identical phases of the active periods of two individual trees of the same species the ratio between the rates of progress of the active period is the same, i.e. the constant k in formula (8) stated on page 73. If that is so, it does not, of course, make much difference at which stage of the active period the rate of progress is measured (cf. also H a g n e r 1970b).

In conclusion, an important principle concerning the active period should be brought up. To someone not very familiar with the matter, it may seem that, according to the model now constructed regarding the active period, it is reasonable to conclude that individual trees that are early at the beginning of the active period, are also early in all the subsequent phases of the active period (and vice versa). However, this need not be the case, because the earliness or lateness of a given individual tree does not depend exclusively on whether it progresses rapidly or slowly in the active period but also on the cessation of winter dormancy. For instance, in a given tree population, those individuals whose winter dormancy comes to an end first, are the earliest at the very beginning of the active period regardless of whether their active period progresses rapidly or slowly. In natural tree populations, between individual trees, the differences in the cessation of winter dormancy are probably comparatively small, from which it follows,

particularly when the active period has progressed considerably, that the sequence then prevailing is usually maintained throughout the rest of the active period.

The situation is different, for instance, in provenience tests, because it often happens that in one and the same test grow proveniences whose winter dormancies come to an end at greatly differing times. The same is true for experiments with different tree species. An illustrative example of them is an experiment with *Larix* species in the Punkaharju experimental area. Of particular interest are *Larix Gmelini* (Kurile Island provenience) and *L. sibirica* (Arkhangelsk, Pinega, and Novosibirsk proveniences). The active period of *Larix Gmelini* is long but the winter dormancy period (DII, to be exact, cf. S a r v a s 1970b) is very short; the active period of *L. sibirica* is short, but the winter dormancy period is much longer than that of *L. Gmelini*. As a consequence, *Larix Gmelini* proveniences regularly flush earlier than *L. sibirica* proveniences do. Later, however, in the progress of the active period, *Larix Gmelini* falls more and more behind *L. sibirica*. By the time the leaves of *Larix sibirica* turn yellow, the difference is often of about 2 weeks (frequently, when *L. sibirica* is golden yellow, *L. Gmelini* is still entirely green).

Incidentally, this example, too, serves to illustrate how superficial our knowledge of the active period will remain until the zero point problem is resolved.

Acclimation

Introduction

The idea has been expressed that, in principle, the active period ends every year at a given temperature sum specific to each genotype, each different meristem, and each different group of living cells. This idea finds support in the evidence accumulated in the course of this study. In consideration of the fact that even in the end portion of the active period, the progress of the active period is controlled primarily by temperature, the above idea is perhaps also the simplest model for reasoning in this connection and makes, therefore, an expedient starting point for the construction of the model.

Examination of such physiological events as seed and leaf abscission, accumulation of starch in the buds, etc., which occur at or after the end of the active period, has, however, revealed a peculiar and very significant phenomenon which in the earlier literature on the subject, most likely, has not been dealt with in detail: it appears that the first low temperatures (below approximately 10°C) in the fall accelerate or induce these phenomena.

That this effect of low temperatures has failed to attract due attention earlier is understandable, for it is hardly possible to get a clear notion of it unless the course of events is observed by applying the principle of the physiological clock, i.e. the p.u. sum rather than calendar time. In this connection, for instance, the degree day principle is no longer serviceable, because the approximation obtained by employing this principle at the low temperatures prevailing in the autumn is too rough.

Another characteristic shared by the above phenomena is that each of them in its own way prepares the tree for the approaching winter. Therefore, in this examination these processes have been compiled under the common heading acclimation (syn. the winter hardning process, cf. W e i s e r 1970).

Seed Abscission

Particularly, the seed abscission of the two birch species growing autochthonously in Finland, i.e. *Betula verrucosa* and *B. pubescens*, has been

observed in the present study over a number of years by making measurements so accurate that the results well elucidate the question under review.

The investigations have been conducted in pure *Betula verrucosa* or *B. pubescens* stands about 2—5 ha in area. Figures describing these stands are shown in Table 1, p. 8. In each stand, 15—20 funnel-shaped seed traps of galvanized sheet iron have been installed. The opening of a trap is 0.05 sq.m. in area. During the first few years of the study, the traps were emptied at 1- or at 2-week intervals and in recent years, at 100- to 200- p.u. intervals (on an average at 2- or at 3-day intervals).

The seeds have been separated in the laboratory from the rest of the residue and counted. They have not been sorted, so the results presented in the following are based on the total number of seeds (filled and empty) collected from the traps. Part of the seed, especially in the case of *Betula pubescens*, abscise gradually during the winter and early spring following the summer of flowering, so these seeds, too, have been collected and treated together with the seeds that had abscised in the late summer and in the autumn. For the sake of brevity, reference is made in the following only to the year of flowering rather than to those of seed abscission.

Seed abscission is best observed in the period unit scale developed above. Let us take Fig. 22 as the starting point for the examination. It shows the data obtained in 1968 concerning seed abscission in two *Betula verrucosa* and two *Betula pubescens* stands growing in Punkaharju and in the nearby commune of Kerimäki. The graphs have been drawn on a frequency net, because it is reasonable to anticipate that in the p.u. scale the amounts of abscised seed more or less conform to the normal frequency distribution. The vertical axis shows the cumulative percentage of the seeds reckoned on the basis of the total amount of abscised seed and the horizontal axis shows the p.u. sum reckoned from the beginning of the year.

The p.u. sum should, of course, be reckoned from its natural zero point, the beginning of the active period, but since we have not yet solved the zero point problem we are forced for the time being to resort to a temporary zero point. The turn of the year suits this purpose equally well or equally poorly as any other point in time. As a consequence of the temporary character of the zero point, the absolute p.u. sums shown by the diagrams are not of appreciable interest. Of significance are the cycle intervals, because they are independent of the position of the zero point.

In examining the diagrams it can be noted that in all the four stands under review the seed abscission has been very similar. It started when the p.u. sum had risen to about 18 000 p.u. and in fact at first conformed to the assumption made concerning the normal frequency distribution. This conclusion can be made because it is possible to fit a straight line to the dot graph as far as about the 50 % ordinate line without violating the data.

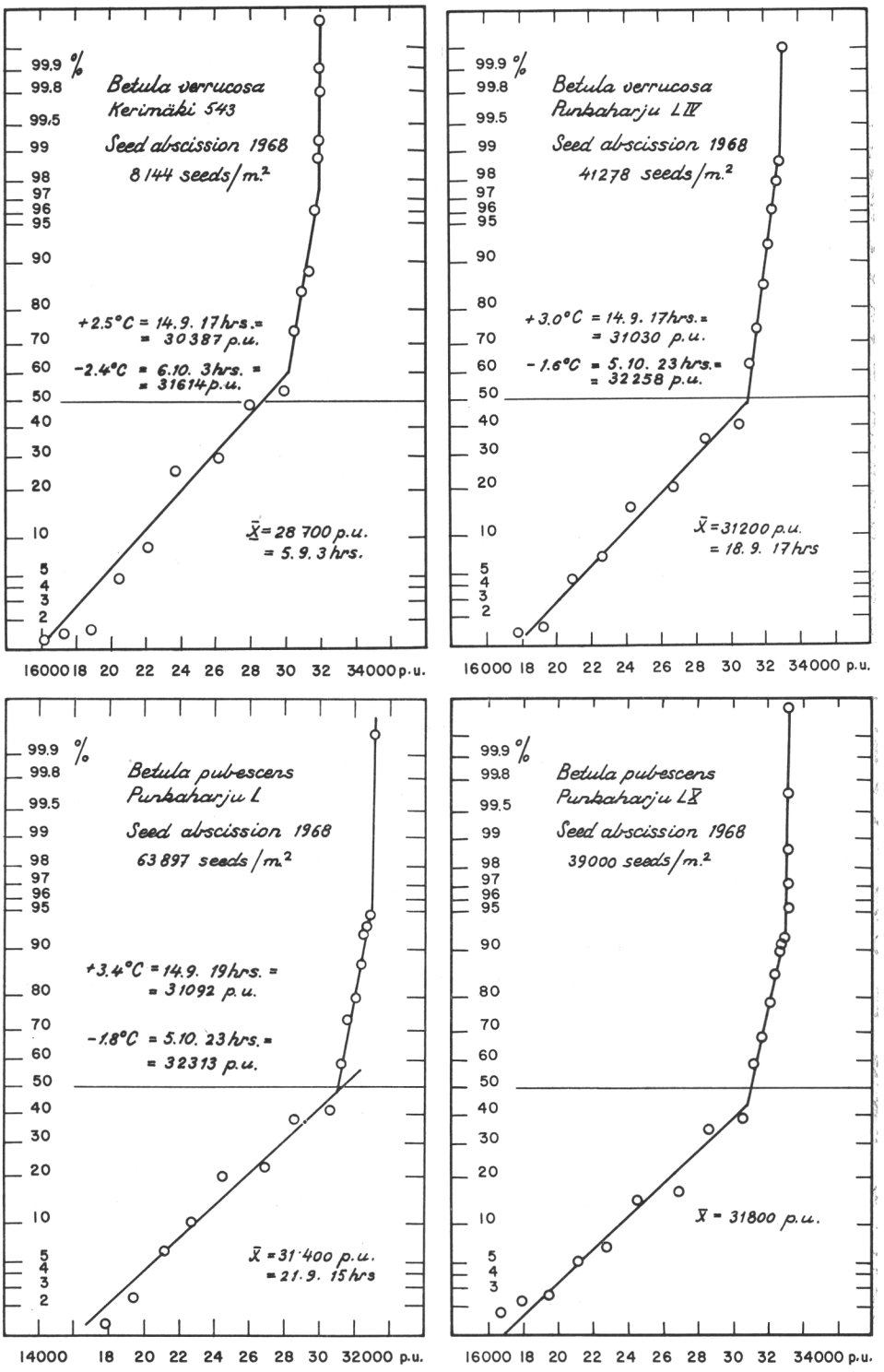

Fig. 22. Seed abscission in two *Betula verrucosa* and two *Betula pubescens* stands in 1968. Scale-frequency net. The horizontal axis shows the **p.u.** sum calculated from the beginning of the year and the vertical axis the cumulative percentage of abscised seeds.

Beyond this line, there is a sudden change in the scatter of dots. However, it is easy to establish that a straight line can also be fitted to the dots in the second half of the frequency distribution, another fraction of the normal frequency distribution, the standard deviation of which is, however, much smaller than that of the first half of the frequency distribution.

What significance do these two fractions of normal frequency distributions and their differing standard deviations have? The following inference elucidates this question. Let us assume 1. that an imaginary seed abscission process has from beginning to end conformed to the frequency distribution of the first half of a real seed abscission process, and 2. that an imaginary seed abscission process has from beginning to end conformed to the frequency distribution of the second half of a real seed abscission process. Apparently, the average abscission rate of the seed would in the former case turn out to be lower than in the latter. If, in both cases, the abscission had occurred under circumstances that were identical in other respects, the ratio between the rates of abscission apparently would have been inversely proportional to the ratio between the standard deviations of the frequency distributions. For instance, in the first picture of Fig. 22, *Betula verrucosa*, Kerimäki 543, the standard deviations are 6 100 p.u. and 1 200 p.u. The ratio between them is 5.10. This can thus be interpreted to mean that the average abscission rate in the second phase of the abscission process is 5.10-fold as compared with the first phase. When all the available material (Figs. 22—25) is taken into consideration, a mean value of 4.93 ± 0.48 will be obtained.

Before advancing any further in our deduction, we should ponder the assumption that »an imaginery seed abscission process has from beginning to end conformed to the frequency distribution of the first half of a real seed abscission process». Actually, in very warm summers this assumption is realized. There is no accelerated phase in the process. Fig. 23 gives an example of this. In *Betula verrucosa*, seed abscission has been controlled from the beginning almost to the end by the p.u. sum.

The ensuing logical question is, of course, what in 1968 caused the sudden increase in the rate of seed abscission.

Those visual observations, on account of which it has long been known (e.g. M o h l 1860) that the first frosts in the fall greatly accelerate the process of leaf abscission in broad-leaved trees, prompt an investigation as to whether a similar impulse is involved in this phenomenon.

In Fig. 22, information is given with respect to three of the 4 diagrams shown, regarding the first low temperatures of the autumn. We immediately notice that the working hypothesis under review seems promising. The first drop in the autumn temperature appears, in fact, to be the particular environmental factor, the impulse that induces the acceleration of the seed abscission process.

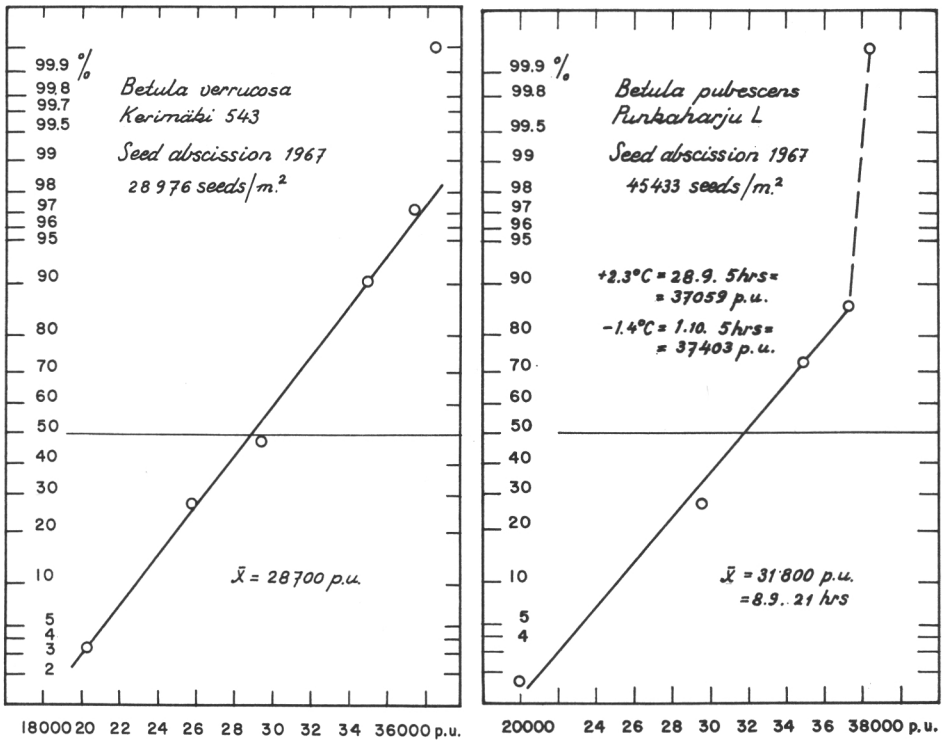

Fig. 23. Seed abscission in a *Betula verrucosa* and a *Betula pubescens* stand in 1967. Scale frequency net. The horizontal axis shows the p.u. sum and the vertical axis the cumulative percentage of abscised seeds.

The dot graphs illustrating the seed abscission process must be divided into three parts. The first part covers the autonomous abscission which, according to our model of the cycle, is controlled by the p.u. sum, the second part covers the accelerated seed abscission induced by the chilling effect, and the third part covers that portion of the seed abscission which is enforced by a frost effect of the kind described by M o h l in connection with the leaf abscission process.

Let us then expand the scope of our review. The results shown in Figs. 24 and 25 pertain to the same experimental stands as the results shown in Fig. 22 but the years of investigation are 1969 and 1970. It may be said that the seed abscission processes in these years were largely similar to that in 1968.

In addition, measurements dating from 1964 as far back as 1956 are available. They were carried out in a *Betula verrucosa* stand located on the grounds of the Ilmala meteorological station in Helsinki. The stand concerned is only about 0.4 ha in area and only one large seed trap (opening 0.5 sq.m.)

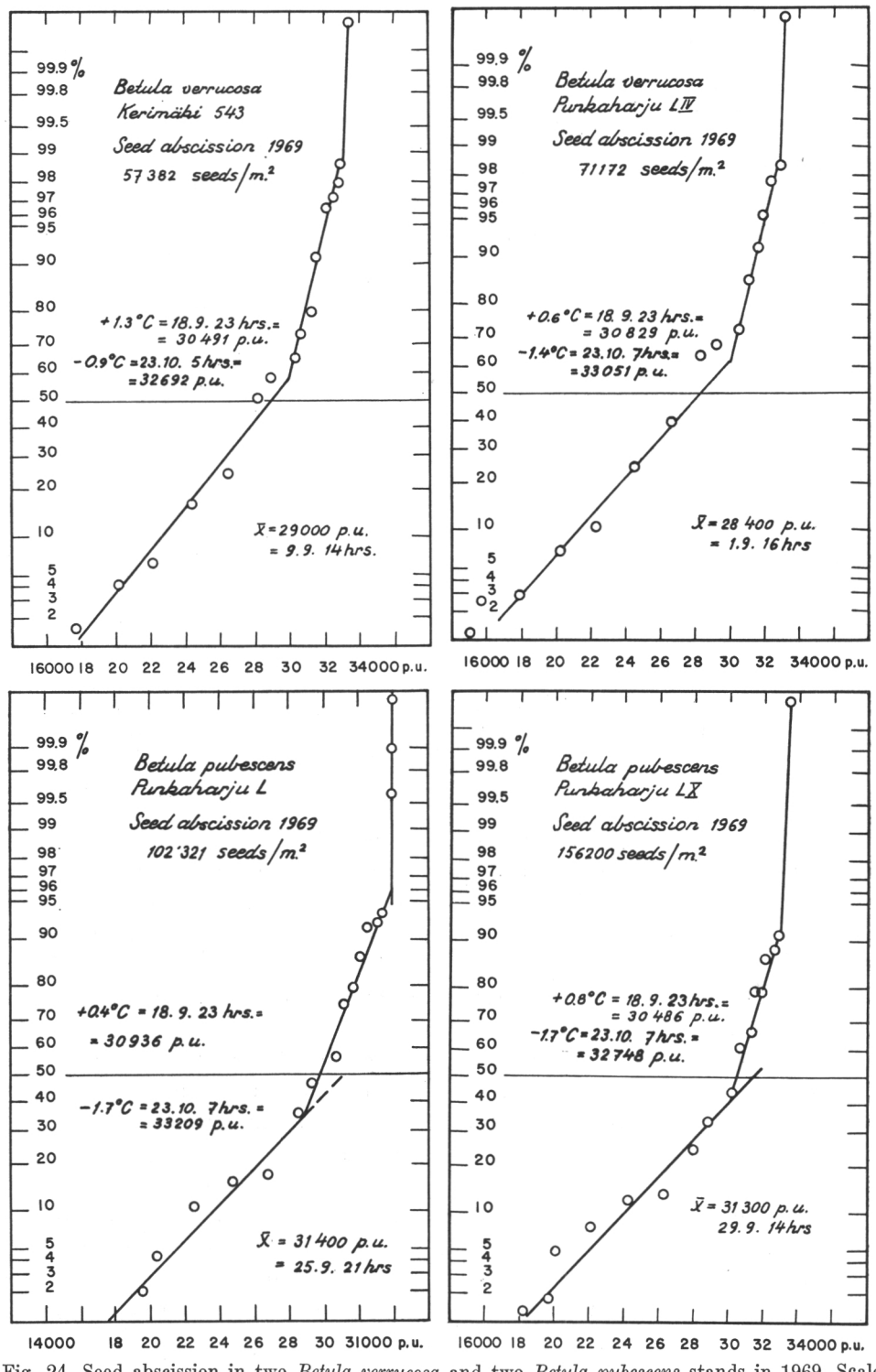

Fig. 24. Seed abscission in two *Betula verrucosa* and two *Betula pubescens* stands in 1969. Scale frequency net. The horizontal axis shows the p.u. sum and the vertical axis the cumulative percentage of abscised seeds.

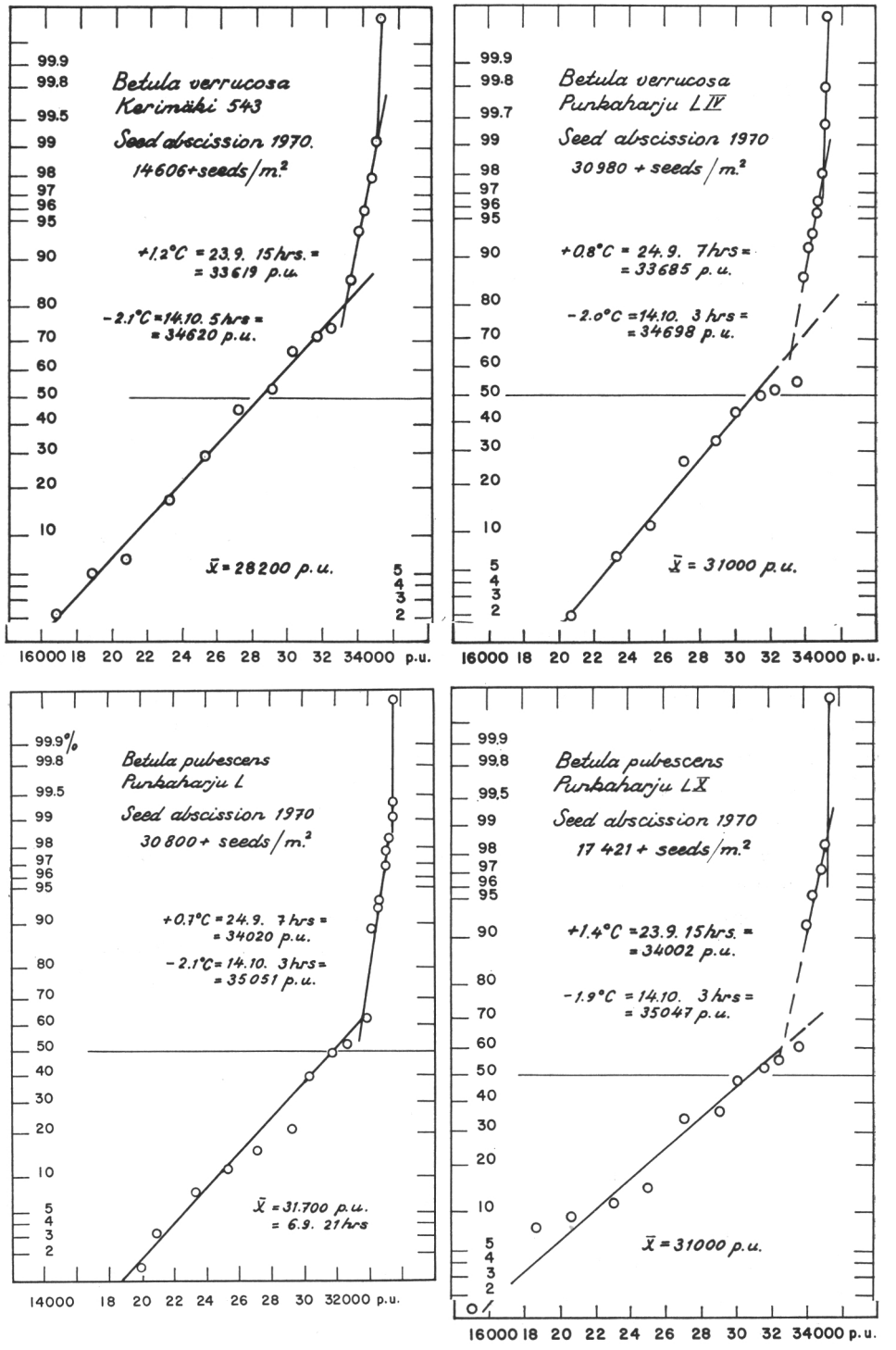

Fig. 25. Seed abscission in two *Betula verrucosa* and two *Betula pubescens* stands in 1970. Scale frequency net. The horizontal axis shows the p.u. sum and the vertical axis the cumulative percentage of abscised seeds.

had been installed there. However, the fact that a first-class meteorological station is located almost at crown level next to the stand enhances the value of the measurements. A detailed examination of them revealed that there is a close relationship between the first drop in temperature and the acceleration of the seed abscission process.

However, while our working hypothesis finds considerable support in this finding, it immediately gives rise to new questions: by how many degrees must the temperature drop, how long must the low temperatures prevail, is the effect of short-duration low temperature conditions between periods of warm weather cumulative, and so forth. Because questions of this nature will be repeated in connection with the examination of dormancy, we shall revert to them after we have dealt with dormancy.

In this connection it is just as well to revert to the frequency distribution of seed abscission and examine in greater detail the unaccelerated portion of it. We have seen that if the first drop in temperature occurs at a p.u. sum high from the seed abscission point of view, seed abscission takes place, in its entirety, without being accelerated. And even in those cases where the end portion of the seed abscission process is accelerated, it is easy to describe by extrapolation what the frequency distribution would have been like if no acceleration had taken place.

On the basis of the general model constructed of the active period, it could perhaps be anticipated that the unaccelerated portions of the frequency distributions were more or less identical, i.e. that they would have the same mean point and the same standard deviation. However, neither anticipation has been realized. The fact that the mean points fail to meet at the same p.u. sum could perhaps be explained as being due to the temporary character of the zero points used but that does not account for the standard deviations being dissimilar.

The dissimilarity of the standard deviations is probably due to the fact that in different years a very different fraction of the tree population under investigation has participated in the flowering process. The smaller the fraction the smaller the standard deviation generally is.

Leaf Abscission

Leaf abscission is a phenomenon that has long fascinated research workers in biology. It also is a phenomenon that seems to give the more surprises the deeper one delves into it.

In the present study, leaf abscission has been investigated particularly in the same *Betula verrucosa* and *B. pubescens* stands in which seed abscission was investigated. The research method, too, has largely been the same:

the leaves in the traps have been collected, counted and their dry weight has been determined. The results have been computed as cumulative frequency sums and they have been examined by means of diagrams drawn on a frequency net.

Figures 26, 27, and 28 show the results pertaining to the measurements carried out in 1968—1970 in three experimental stands located in Punkaharju and its vicinity (Kerimäki).

It can be seen immediately that the data are largely similar to those obtained in respect of seed abscission. The frequency distribution of the p.u. sums of leaf abscission is composed of three portions that can easily be distinguished from one another, namely the unaccelerated portion, the accelerated portion, and the one enforced by frost.

As in the seed abscission process, it can be established that the ratio between the average abscission rates before and after acceleration equals the ratio between the standard deviations of the frequency distributions concerned. By taking advantage of this, it can be calculated that in the leaf abscission processes described in Figs. 26, 27 and 28, the average acceleration has been 5.0-fold. There is no appreciable difference in this respect between *Betula verrucosa* and *Betula pubescens*.

It is worthwhile even closer to compare the seed and leaf abscission processes with each other. It can be seen that in both cases the onset of acceleration occurs approximately at the same (calendar) time, first in the leaf abscission process and somewhat later in the seed abscission process and, further, that the same is true for the initiation of frost effect.

Even though these portions are analogous they differ very much in length (in terms of p.u. sums). As regards seed abscission, in most years the autonomous portion comprises 40—60 % of the total amount of abscised seed, whereas in leaf abscission the corresponding proportion is only 5—10 %. The accelerated portions of the seed and leaf abscission processes are of about the same magnitude (40—50 %). In the portion enforced by frost, the difference in question is, again, of a greater magnitude: in seed abscission, this portion makes up 5—10 % of the total abscission, and in leaf abscission, 50—80 %. Thus, even though the seed and leaf abscission processes qualitatively conform to a common pattern, there are large quantitative differences between them. These differences result from the fact that in the annual developmental cycle, seed abscission is an earlier physiological phase than leaf abscission.

Thus, it would seem that the annual variation that can be observed in the leaf abscission process is controlled largely by the thermal factor (i.e. the thermal factor, including the acceleration impulse, seems to account for a high percentage of the annual variation). If the abscission process were controlled primarily by the p.u. sum alone (or by length of day, photo-

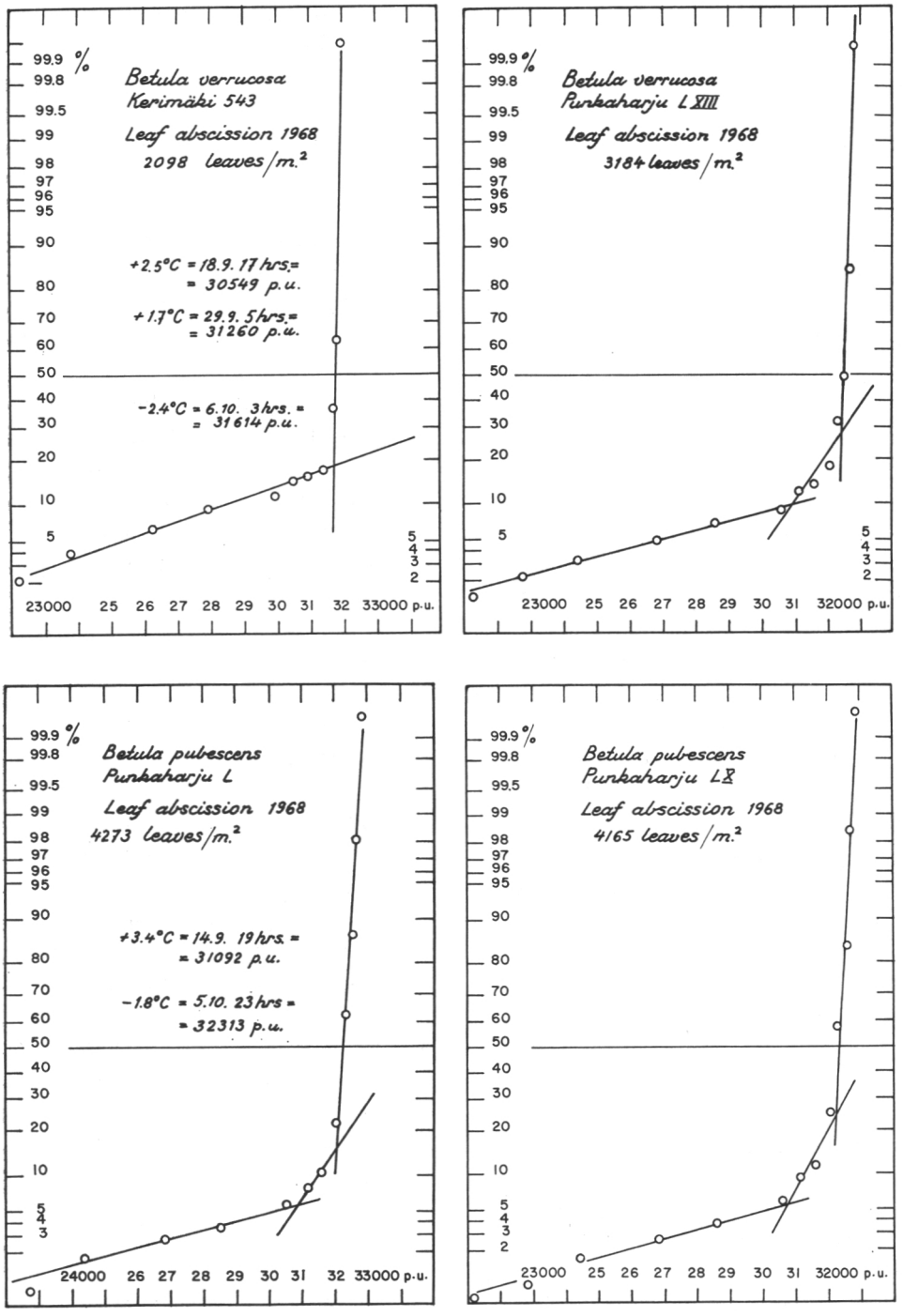

Fig. 26. Leaf abscission in two *Betula verrucosa* and two *Betula pubescens* stands in 1968. Scale frequency net. The horizontal axis shows the p.u. sum and the vertical axis the cumulative percentage of abscised leaves.

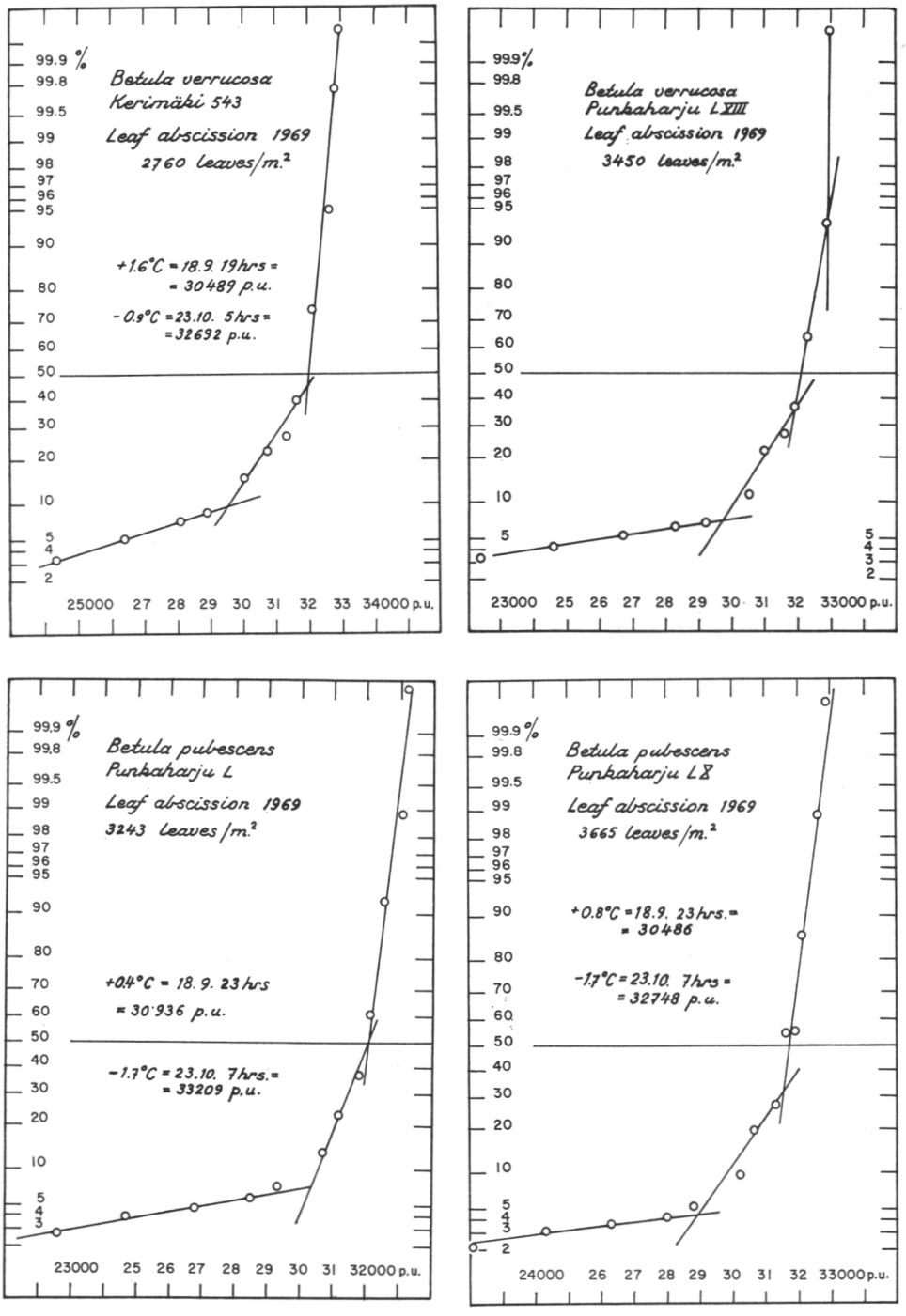

Fig. 27. Leaf abscission in two *Betula verrucosa* and two *Betula pubescens* stands in 1969. Scale frequency net. The horizontal axis shows the p.u. sum and the vertical axis the cumulative percentage of abscised leaves.

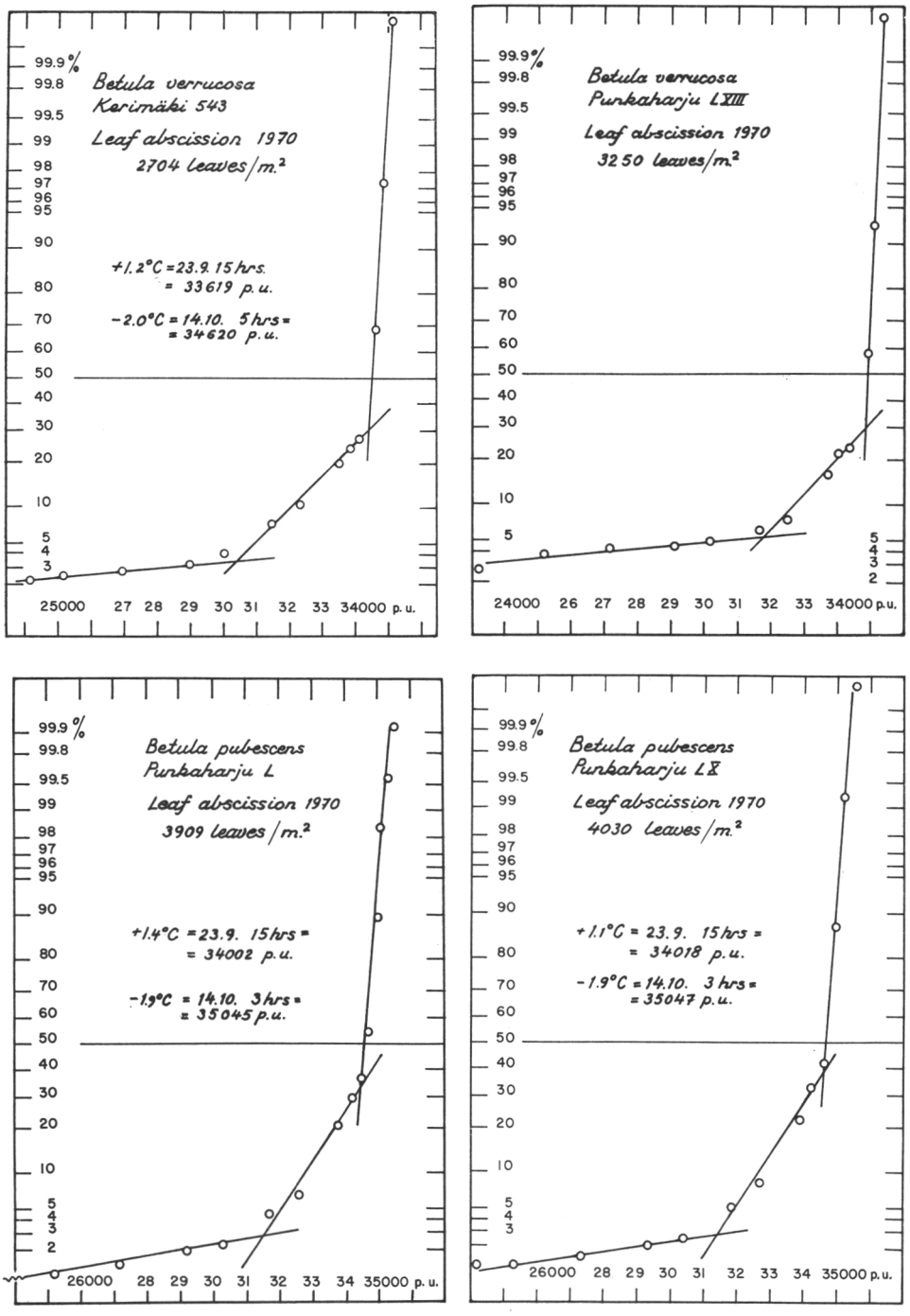

Fig. 28. Leaf abscission in two *Betula verrucosa* and two *Betula pubescens* stands in 1970. Scale frequency net. The horizontal axis shows the p.u. sum and the vertical axis the cumulative percentage of abscised leaves.

periodism) it could be expected that the frequency distribution in the p.u. scale would be normal (or, where a phenomenon controlled by photoperiodism is involved, it could be expected that the frequency distribution in the calendar time scale would be normal). However, neither alternative has materialized.

It should further be noted that the standard deviation of the unaccelerated portion of the leaf abscission process is surprisingly large. It is very much larger than the standard deviations of many other cardinal events of the active period, the variation coefficients of which are of about the 0.06 class of magnitude. It should be noted that although in Punkaharju (but not in the most northern parts of Finland) the initiation of the leaf abscission process seems to be controlled in most years by the p.u. sum, it seldom happens that even 20 % of the leaves have abscised by the time the first low temperatures in the fall interfere with the process and accelerate it. Hence, acceleration dominates the leaf abscission process to a much larger extent than it dominates the seed abscission process. As a matter of fact, it remains somewhat unclear as to whether it is reasonable at all to speak of an autonomous fraction that is controlled by the time - temperature factor. This portion is so small that it might be explained adequately by other causes, such as a strong wind, drought, and the damage caused by insects and fungi. An interpretation of this kind would thus mean that it is the first low temperatures of the autumn that actually induce the leaf abscission process. — The question arises as to whether (leaf abscission should at all thought of as a phenomenon typical of the annual cycle.

As has been mentioned before, leaf abscission is a plant physiological phenomenon that has fascinated the minds of research workers for a long time. One of the earliest studies concerned with it was published by no less a scientist than Hugo v. M o h l (1860) and was entitled: Ueber die anatomischen Veränderungen des Blattgelenkes, welche das Abfallen der Blätter herbeiführen. As the title implies, the study concentrates on the anatomic aspect of leaf abscission even though the author also draws conclusions regarding plant physiolology from the experimental results he has accumulated. Even today, the publication is probably ranked as one of the most comprehensive papers ever to have come out regarding this phenomenon. In respect of research work carried out in recent decades, several good abstracts including, for instance, C a r n s 1966, have been published and reference is made to them.

The above publication by M o h l first gives a thorough and interesting account of what had been published by 1860 concerning leaf abscission and, particularly, its anatomy. M o h l shows on the basis of comprehensive anatomic investigations that leaf abscission is an active phenomenon that is controlled by the plant (tree) and that it results from the development

of a specific abscission tissue in the parenchyma at the base of the petiole. In a given cross section of the petiole the parenchymatous cells turn meristematic through rejuvenation, undergo a few divisions and only some weeks before leaf abscission form an abscission layer. The actual abscission process is brought about by disintegration of cell walls in the abscission layer. M o h l's idea of the physiological background of leaf abscission is very interesting. He discerns in it primarily 3 different series of phenomena which more or less overlap one another: 1. the process of gradual deterioration associated with the aging of leaves; 2. the accelerative influence exercised by the unfavourable weather conditions of the autumn, and 3. the mechanical effect of frost. It is appropriate here to quote some passages of this excellent publication of M o h l's (pp. 14—15): »Es ist allerdings richtig, dass ein jedes Blatt eine bestimmte Lebensdauer besitzt und dass ein jüngeres Blatt fähig ist, äusseren ungünstigen Umständen kräftigeren Widerstand zu leisten, als ein älteres Blatt, allein es ist nicht richtig, das Abfallen des Blattes bloss von der Dauer seiner Lebenzeit abzuleiten, wir müssen im Gegentheile annehmen, dass unter unseren klimatischen Verhältnissen die Blätter sehr vieler bei uns einheimischer Holzgewächse eines durch die ungünstigen Verhältnisse unserer herbstlichen Witterung eingeleiteten frühzeitigen Todtes sterben. — — — Wenn die längere Zeit fort einwirkende ungünstige Herbstwitterung die Blätter zum langsamen Absterben bringt und dadurch eine frühzeitigere Entwicklung der Trennungsschichte, als sie unter anderen Umständen eingetreten wäre, veranlasst, so verhält sich dagegen die Art und Weise, wie die Blätter durch einen plötzlich eintretenden stärkeren Frost zum Abfallen gebracht werden, wesentlich anders». In these vivid descriptions the three phases of the phenomenon of leaf abscission are discerned as they also are in the diagrams shown in Figs. 26—28: 1. the phase controlled by the p.u. sum (or age), 2. the accelerated phase induced by the low temperature effect and subsequently controlled by the p.u. sum and 3. the phase that is under the mechanical influence of the frost but is independent of the p.u. sum.

The phenomenon of leaf abscission is easier to investigate experimentally than the phenomenon of seed abscission. On account of this an attempt was made to test the working hypothesis advanced above, according to which the first appreciable drop in temperature in the autumn would be the environmental factor that causes the acceleration of the rate of abscission. So far, there has been time to perform only one pilot test, namely in the autumn of 1971. The material experimented with comprised 1/0-year seedlings grown in a nursery. They were treated at different temperatures under varying periods of time. The seedlings concerned were lifted from the nursery on September 8, 1971 and moved into the greenhouse where the temperature was about 15°C. During a few cold nights prior to lifting from the nursery, the seedlings had been at temperatures below 8°C. Since temperature measurements did not take place at the height of seedlings, it is not known how low the temperature dropped.

Higher up, at a level of 2 meters, the lowest temperature, 1.9°C, was measured on September 8. It can be estimated that prior to the lifting of the seedlings, the temperature at the height of 2 meters stayed below 5°C for a total of 20 hours. At seedling height, the corresponding time can be estimated at about 60 hours. The temperatures employed in the experiment were: —1.5, —0.5, 2.0, and 4.0°C. In addition, a number of seedlings were kept at 15°C as controls. The treatments involved lasted for 3, 6, 12, 24, and 48 hours. The experiment was begun at 8.00 a.m. on September 28. Following the treatments, which took place in the dark, the seedlings were brought into the greenhouse where the temperature was 15°C. Each day, between 8.00 and 8.30 a.m. the seedlings were examined and the leaves that had abscised were counted and removed. The findings indicated that most of the treatments had accelerated the abscission rate as checked against the control. On the other hand, there were no significant differences in the influence exercised by the different temperatures employed. The shortest treatment period, 3 hours, had not been adequate to bring about a measurable effect, whereas a 6-hour treatment was long enough to effect maximal acceleration. After this had been established, the results pertaining to treatments that lasted longer than 3 hours were combined. Comparison with the control is illustrated by Figs. 29 and 30. The scale is frequency net. The horizontal axis shows the time measured between the completion of treatments and the observations, and the vertical axis the percentage of leaves (calculated on the total number) that remained on the seedlings. Fig. 29 shows the result thus obtained. The control is marked with circled dots and the combined treatments, with slanting crosses. In addition, free-hand straight lines have been fitted to the dot and to the cross graphs. The line

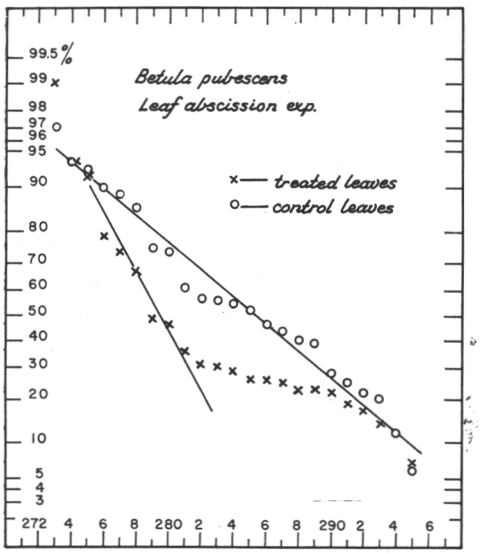

Fig. 29. Results of leaf abscission experiment. The horizontal axis shows the successive numbers of days and the vertical axis the percentage of leaves that have not yet abscised.

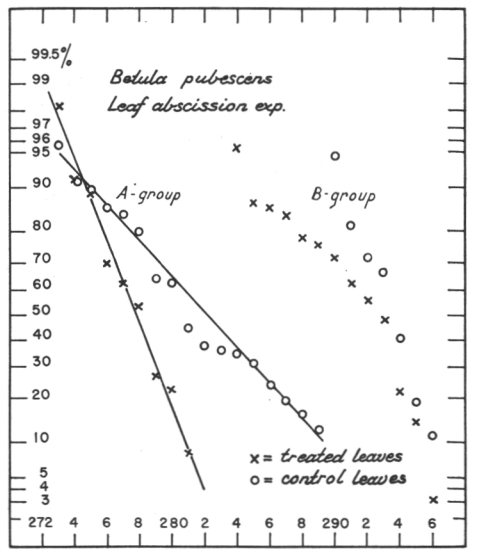

Fig. 30. Same experimental results as in Fig. 29. The treated and the untreated leaf populations have been divided into two subpopulations: A. (left) 70 % of the leaves (those that abscised first) and B. (right) remainder of the leaves.

fitted to the dot graph does not violate the data too much, but the same cannot be said of the line fitted to the crosses. However, to them, too, a straight line can be fitted in so far as more than 30 % of the leaves remain on the seedlings. After that, the behaviour of the cross graph is so devious that no attempt has been made to combine it with the forward portion of the graph.

As regards the cause of the extraordinary behaviour of the cross cluster representing the treatments, it can be speculated that the treatments have affected only about 70 % of all the leaves (perhaps the oldest ones) but not the remaining 30 %. In Fig. 30, this possibility is studied more closely. The treated leaves have been divided into 2 groups. The first group (A) comprises 70 % of the leaves (those that had been abscised first) and group B comprises the remaining 30 % of the leaves. The abscission rate is shown separately for either group. In addition, either group is checked against the control: group (A) is checked against the 70 % of leaves that had abscised first, and group (B) against the leaves that had abscised later. Furthermore, Fig. 30 shows that in group (A) the abscission rate of the treated leaves is higher than that of the untreated leaves (the difference is highly significant), whereas in group (B) the abscission rate of the treated leaves deviates less from that of the untreated leaves.

In studying Fig. 30 it should further be noted that the treatment had no immediate effect on leaf abscission but rather the acceleration of the rate of abscission began only 3—5 days after the treatment. Thus, the test lends support to the idea that low temperatures have an accelerative effect on the leaf abscission process. However, being a pilot test, it has not managed to clarify in detail the relative differences between the different temperatures nor as regards the time required. It should be noted, however, that a temperature as high as 4°C has been (within the accuracy range of the test) highly effective.

The observation that the treatment does not seem to have had any effect on all the leaves is very significant. Thus, on the basis of the cycle model of the annual development constructed in the course of this study it is reasonable to speculate that the treatment is not effective until the active period has reached a given developmental stage (cf. M a g n e s e n 1971, p. 266). Since it is a characteristic of 1-year birch seedlings that new leaves are produced even at the very late phases of the latter part of the summer, it seems that in the material treated there were large differences between the developmental phases of the different leaves.

The view that acceleration cannot be brought about at a too early stage of development, but that it occurs only after the development has reached a given stage finds support in some scattered observations made in nature.

For instance, in the Punkaharju experimental area it can be noted year after year that the first drop in temperature has no accelerative effect on the leaf abscission in *Quercus borealis* Michx. grown for ornamental purposes. Evidently, the active period of this tree species, in terms of the p.u. sum, is so long that at Punkaharju it practically never progresses far enough for the acceleration to take place.

Similar observations can be made in northern Finland in respect of authochthonous tree species. For instance, the summer of 1968 was exceptionally cold in northern Finland. At Sodankylä located in the middle of this area, the p.u. sum of the whole year rose only to 627 d.d. while the mean of the years 1908—1969 was 777 d.d. At the onset of winter, the leaves,

still more or less green, clung to the trees, and, only after they had been bitten by the frost and torn by winter storms did they fall, one by one, to the ground.

It is obvious, however, that as long as the problem pertaining to the zero point of the active period remains unsolved we shall fail to get a clear notion of how far the active period must progress before acceleration can take place. And even after the zero point problem has been solved, it will probably take a considerable amount of work, time and money to reach the goal.

Leaf abscission is not a phenomenon that attracts the attention of research workers alone but also fascinates laymen interested in nature. A few details that have become the object of widespread interest will as a result of what has been stated above be increasingly easy to understand.

In the autumn when the leaves have started turning yellow it is easy to see that in young 2—3 m. tall birch trees the leaves that start turning yellow first are located in the centre of the crown and that the phenomenon extends toward the periphery. This is explained by the fact that particularly in fairly young birch trees, the age difference between the leaves attached to the dwarf shoots in the centre of the crown and the leaves attached to the long shoots situated in the periphery of the crown is considerable. On account of this, the active period of leaves ends earlier in the centre than in the periphery of the crown. In mature birch trees, the majority of leaves are attached to dwarf shoots. In them the age differences are small and, therefore, the phenomenon is not clearly visible in mature trees.

In mature trees, on the other hand, the periphery of the crown turns yellow (or reddish) earlier than the centre. This is particularly true for *Acer* species. The phenomenon may result from the outer portions of trees being sooner exposed to the effect of low temperatures.

The observations of a similar nature, published by D i n g l e r (1902, pp. 200—203) as early as the beginning of this century should be recalled. He noted that where trees (*Populus tremula v. fastigiata*) had been cut in the winter, development of the sprouts was delayed by about a month and, correspondingly, the leaves stayed on the trees till the winter set in. On the basis of his observations D i n g l e r (p. 198) concludes: »Daraus liesse sich einerseits schliessen, dass die Blätter einer bestimmten Holzart normal ein gewisses, nennen wir es physiologisches Alter erreichen und dann aus irgend einem inneren Grunde, nennen wir ihn einmal ohne Präjudiz Altersschwäche, absterben».

One detail still deserves attention. In the foregoing, when seed and leaf abscission was surveyed, attention was paid to the accelerative effect that the first cold spells of the autumn have on these physiological processes. It should, however, be established that even when accelerated, these pro-

cesses are not particularly rapid as compared with the phenomena taking place in the first half of the active period. When the progress of the active period is surveyed on the population level, the standard deviation of the frequency distribution (reckoned in p.u. scale) of the point of attainment of a given physiological phase (50 %) clarifies the rate of progress at least to some extent (cf. page 80). A variation coefficient smaller than average can be interpreted to be an indication of a high rate of progress, and a large variation coefficient may be said to signify a low rate of progress. For instance, the standard deviation of the unaccelerated portion of seed abscission is on an average 6 100 p.u., and the variation coefficient averages 0.2; similarly, the standard deviation of leaf abscission averages 19 000 p.u. and the variation coefficient, 0.3. According to results published earlier (Sarvas 1967, p. 223), the variation coefficient pertaining to the physiological phenomena of the active period (on the population level) is about 0.06. As a result of acceleration, the variation coefficient of seed abscission rises to about 0.04 and the variation coefficient of leaf abscission to about 0.06. After the acceleration, the variation coefficient thus drops approximately to the level at which it is generally in the active period.

Starch

Seed and leaf abscission are phenomena suggestive of that acceleration of the end portions of these processes has taken place, but they may also give rise to speculation of whether the end portions are actually accelerated or whether the phenomena in question are merely the result of injuries inflicted by the drop of temperature rather than of actual aitionomous acceleration. Observations concerning the starch granules in the microspores of certain tree species are more informative in this respect.

In examining microscopic preparations pertaining, for instance, to the male buds of the *Betula*, *Alnus*, and *Corylus* species it can be seen that at a certain developmental phase, which in southern Finland falls between September 15 and October 15, microspores display large granules of starch which finally fill the whole microspores. Almost immediately after this the starch granules disappear.

In the present study, the appearance and disappearance of starch granules were observed in the microspores of *Betula verrucosa*, *Betula pubescens*, *Alnus incana* and *Corylus avellana*. The observations were carried out in the Punkaharju experimental area in the autumn of 1970. The investigatory method is as follows: in the autumn, at 2- to 3-day intervals, a total of 5 male buds (catkin buds) are taken from different sides of the crown of a single individual tree (of each of the above-named species) and from

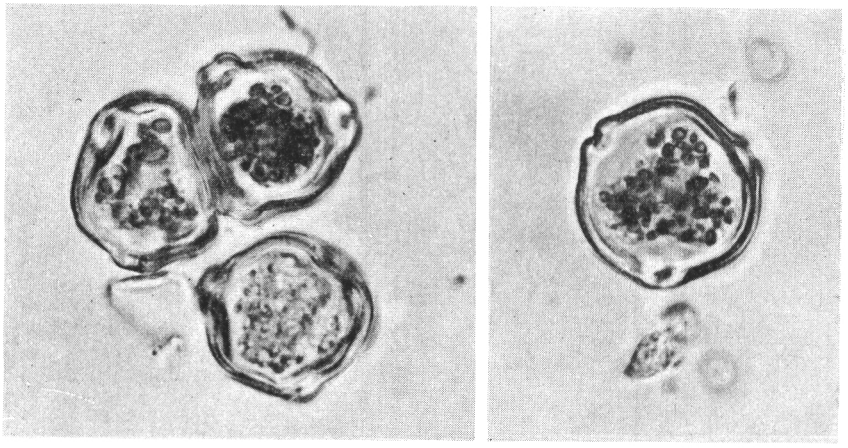

Fig. 31. Microspores of *Betula pubescens*. Three microspores are filled with starch granules. In the fourth, the lowest one, the granules are not yet fully developed and iodine solution does not stain them blue. Punkaharju L, fixed on Oct. 5, 1971.

each of these buds, 10 pollen sacs of the anthers are dissected. All the pollen sacs are mixed and a squash is made by employing the iodine method. The iodine used was a mixture of 0.1 g. iodine, 0.4 g. potassiumiodide, and 30.0 g. distilled water.

In the microscopic examination, the microspores were divided into two groups: 1 (sign minus) starch fills less than 50 % of the cubic content of microspore and 2 (sign plus) starch fills 50 % or more of the cubic content of microspore (Fig. 31). In the following, for the sake of brevity, microspores filled 50 % or more are referred to as microspores filled with starch. The results of the investigations involved are seen in Fig. 32 in the form of graphs on a frequency net. The horizontal axis shows the p.u. sum reckoned from the beginning of the year, and the vertical axis shows the percentage of microspores that have been given the plus sign. The first minimum temperatures appeared approximately as indicated in Fig. 28.

It is probably most beneficial to examine first the diagram pertaining to *Betula verrucosa*.

A straight line can be fitted to the dot graph showing the accumulation of starch, which means that the frequency distribution of the p.u. sums of the occurrence of starch approaches the normal frequency distribution. The mean value is $\bar{x} = 29\,650$ p.u. (standard deviation $s = 1\,600$ p.u.), which means that when the autumn had advanced this far, about half of the microspores were filled with starch. When the p.u. sum had risen to 31 750, about 99 % of the microspores were filled with starch.

Immediately after the peak has been reached, the starch begins to dwindle. Again, to the first portion (approximately as far as the p.u. sum

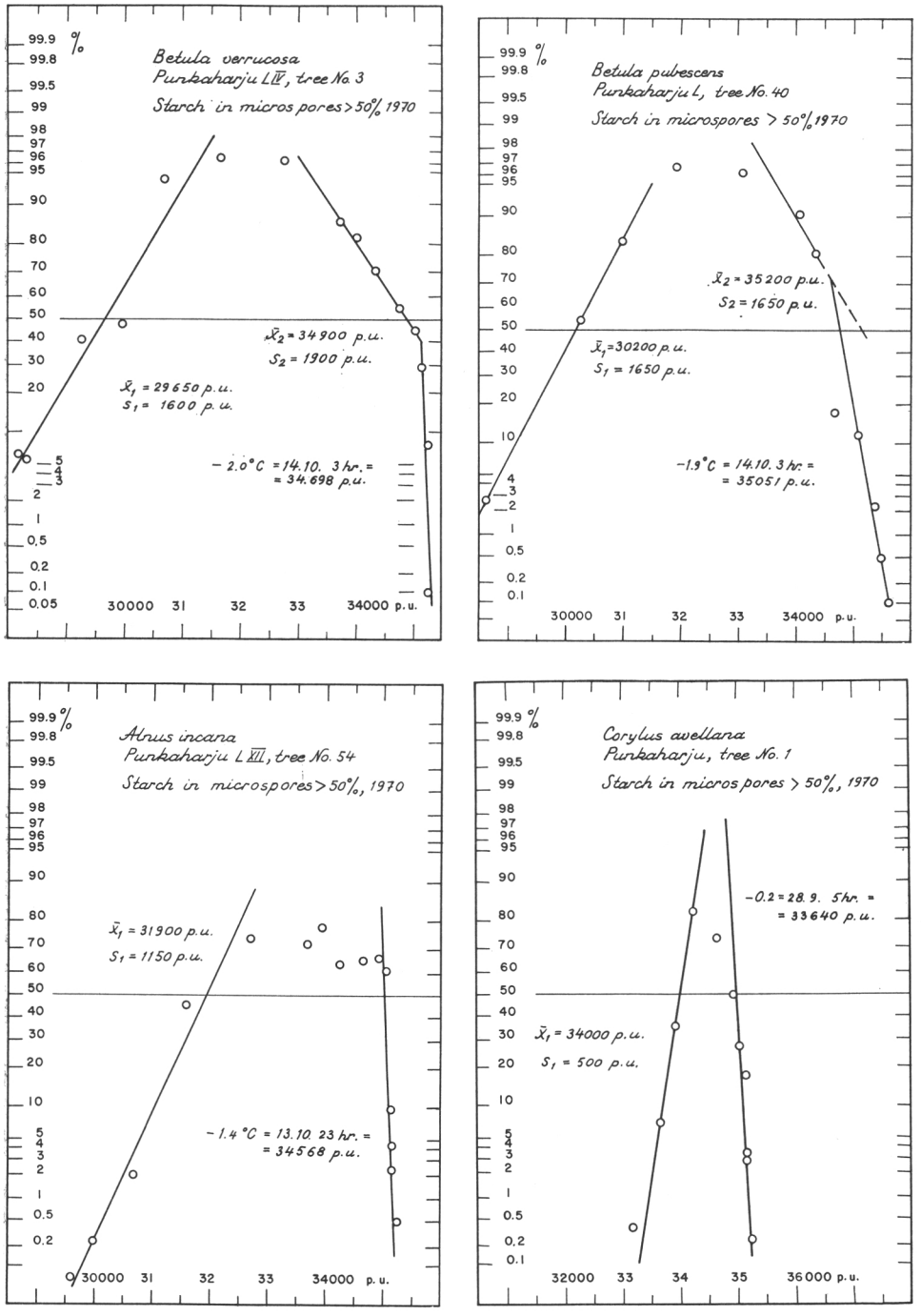

Fig. 32. Starch grains in the microspores of *Betula verrucosa*, *B. pubescens*, *Alnus incana*, and *Corylus avellana* in 1970. Scale frequency net. The horizontal axis shows the p.u. sum and the vertical axis the cumulative percentage of microspores that contain starch granules more than 50 % of their capacity.

of 35 000) of the dot graph that indicates the dwindling trend, a straight line can be fitted, the standard deviation of which is of the same class of magnitude (s = 1 900 p.u.) as of the frequency distribution illustrating the accumulation of starch.

On the other hand, the second portion of the dot graph that shows the dwindling of the starch differs sharply from the first portion. It can, however, be noted that a third straight line, the standard deviation of which is about 100 p.u., can be fitted to the second portion of this graph.

As in the examination of seed and leaf abscission made in the foregoing, the smaller standard deviation can also in this connection be considered to indicate that by the time the p.u. sum has risen to 35 000, there is a sharp increase in the rate of dwindling of the starch. In this case, it is tempting to assume that the acceleration is due to the first frost that coincides with the p.u. sum of 34 698 (—2.0°C).

In the microspores of *Betula pubescens*, the appearance and disappearance of starch largely follow the same pattern as in the microspores of *Betula verrucosa*. The mean value of the appearance of starch is slightly higher, $\bar{x}$ = 30 200 p.u., as is the mean value of the early phase of the disappearance ($\bar{x}$ = 35 200 p.u.). Because the sampling has taken place at the individual level, the differences, of course, do not in any way bear on differences possibly existing between different species. In *Betula pubescens* (Fig. 32), the accelerated phase of the disappearance set in earlier than in *B. verrucosa*. The *B. pubescens* stand, where tree No. 40 grows, is a colder growing site than where *B. verrucosa* grows. It is interesting to note that after acceleration has taken place, subsequent low temperatures have had no further intensifying effect on the acceleration.

The graph pertaining to *Alnus incana* (Fig. 32) hardly displays anything essentially new. Only, the accumulation of starch begins at a slightly higher p.u. sum than in the *Betula* trees examined. It may be due to the smaller size of tree and the colder growing site that in *Alnus incana* the onset of the accelerated phase in the dwindling of starch occurs even earlier than in the *Betula pubescens* examined. In fact, the accelerated phase almost covers the entire dwindling process.

Corylus avellana is not likely to grow autochthonously in Punkaharju. The origin of the individual tree under review is uncertain. At first sight, the diagram displaying the appearance and disappearance of starch (Fig. 32) does not differ essentially from those examined above. However, a closer scrutiny reveals that in *Corylus avellana*, the accumulation of starch begins much later than in the tree species previously examined. This is evidently the reason why the major portion of the starch accumulation process has also come within the sphere of the accelerative influence (the first frost, —0.2°C, occurred at a p.u. sum of 33 640). This finding also finds support

in the fact that the standard deviations of the frequency distributions of the p.u. sums of the appearance as well as the disappearance of starch are of the same class of magnitude (about 100 p.u.) as the corresponding value stated above for the accelerated portion of the dwindling of starch. The fact that the acceleration is brought about in an early part of the cumulative phase is probably enough to explain why in respect of *Corylus avellana*, the frequency distributions of the p.u. sums of the appearance and of the disappearance of starch overlap each other considerably more than they do in regard to the *Betula* and *Alnus*.

However, even though the accelerated phases of the appearance and disappearance of starch resemble the corresponding phases observed in the seed and leaf abscission processes, it should be noted that in the case of starch, acceleration occurs at a later date as a result of the first frosts of the autumn. The acceleration of starch thus coincides with the 3rd phase of the seed and leaf abscission processes.

Acclimation and the Annual Cycle of Development

Of the physiological processes examined in the foregoing, the appearance and disappearance of starch are no doubt the ones most directly associated with the acclimation phenomenon. Also the yellowing of leaves and leaf abscission appear to be phenomena with which biochemical processes important from the acclimation point of view are associated. A phenomenon less closely associated with acclimation is seed abscission, and the only reason that findings concerned with it have been presented is that seed abscission in the birch is perhaps the phenomenon that most clearly displays the accelerative effect that the first low temperatures of the autumn have on abscission.

The acclimation process can hardly get properly started until the active period of the cell or cellular tissue concerned is over. For instance, in *Larix decidua*, at the first stages of the acclimation process, a large amount of starch accumulates in the microspore mother cells but it can hardly ever be observed until the active period of mother cells has progressed as far as the end of the pachytene phase or the diplotene phase. This means that the first stages of the acclimation process take place at the very end of the active period or during the first phases of dormancy. Thus, there is a certain point here which the acclimation process and dormancy have in common.

The acclimation process is, above all, a series of physiological events the sole purpose of which is to change the physiological state of the cells

and cellular tissues involved from frost-susceptible to frost-hardy. However, it may not be appropriate to regard the acclimation process as being part of the annual cycle in the way the active period and dormancy are. Evidently, the cycle progresses from the active period to dormancy and, further from dormancy to the active period irrespective of whether or not acclimation has developed well. The cycle is a mere timetable that need not have any other functions. This is particularly true for frost-hardiness. Dormancy arrests given physiological processes of live cells at a phase best suited for acclimation to occur, but dormancy that lacks acclimation (a possibility that is not out of the question) is not likely to improve materially frost hardiness (cf. L e i k e 1965, p. 481).

In addition, the acclimation processes differ from the physiological processes that further the cycle in that to some degree they appear to be reversible, whereas at least none of the observations made in the course of the present study contradict the concept that the cycle is an irreversible chain of phenomena.

In the acclimation process, as it is seen in the light of the observations made in the present study concerning the appearance and disappearance of starch, two phases can be distinguished, i.e. the phase induced by the first low temperatures in the autumn (below 10°C) and the one brought about by the freezing temperatures.

Of great significance is the observation that although low temperatures have an effect that either induces or accelerates acclimation, the process of acclimation itself is most rapid under high temperature conditions. The rate of progress of acclimation seems to be controlled by temperature in about the same way as the rate of progress of the active period is. Thus, this constitutes a point which the acclimation phenomenon and the progress of the active period have in common.

It seems possible that a prerequisite for good acclimation is that the first phase is long (in terms of p.u. sums). However, no accurate figures are available as yet. Obviously, in many cases the first frost forcibly intercepts a number of the physiological processes that make up the acclimation process and accelerates the others. It is likely that the earlier the frost occurs during the acclimation process the more undeveloped will the acclimation remain. The winter 1968/69, among others, provides a good example of this (cf. Figs. 22 and 26). After this winter, particularly in northern Finland, damage caused by frost could be observed almost in all foreign tree species and in some of the autochthonous ones, too.

Acclimation of tree-like plants has been discussed extensively in the literature of the subject. Particularly, the biochemistry of the acclimation process has been the subject of widespread interest. In the present study, most attention has been paid to the joint effect of time and temperature.

Thus, good acclimation depends largely on the specific temperature conditions of the autumn. However, the growing season in its entirety is likely to influence acclimation, for generally only those cellular tissues which have completed their active period can acclimate well. Also, a good nutritional balance must be considered to be one of the factors contributing to good acclimation. Hence, it is reasonable to anticipate that a favourable growing season creates a good background for acclimation.

However, good acclimation is not necessarily synonymous with good frost hardiness. Obviously, well-acclimated live cells endure frost better than do poorly acclimated ones. The latter are hardier than the ones still in the active period but, as a rule, good frost hardiness develops gradually as the temperature gradually drops at the approach of midwinter. Frost hardiness, too, appears to be a reversible phenomenon, the intensity of which increases and decreases depending on temperature fluctuations. It is well to bring up these opinions (cf. e.g. Leike 1965, pp. 481—482, Weiser 1970, Perry 1971, Sakai and Okada 1971) of the general character of the acclimation process which have won increasing support in the last two decades; the conclusions reached in this study regarding the relationship between the annual cycle of development and the acclimation process are not in conflict with them.

Summary

The starting point for the study was the earlier finding that the progress of the active period appears to be dependent almost exclusively on the time-temperature factor. The cycle interval of the active period is assigned a unit (period unit, abbr. p.u.) that is defined as being 1/5 of the cycle interval that the active period of a given genotype progresses in 1 hour at a temperature of 10°C. Thus, under constant thermal conditions the following equation prevails

$$P_1 \rightarrow P_2 = v\,(T)\ (t_2 — t_1) \tag{1}$$

in which $P_1 \rightarrow P_2$ is the cycle interval between times t_1 and t_2, T, the constant temperature and v the rate of progress of the cycle. Where the temperature continuously fluctuates, as in nature, the equation can be written in the form

$$P_1 \rightarrow P_2 = \int_{t_1}^{t_2} v\,(T(t))\,dt \tag{2}$$

For the sake of practical calculations, e.g. automatic data processing, equation (2) can be approximated in the form

$$P_1 \rightarrow P_2 = \sum_{i=1}^{n} v\,(Ti)\,t_i \tag{3}$$

in which i is the ith temperature measurement when the time lapse between P_1 and P_2 has been divided into n equally long periods. In equations 1—3, v is the only unknown. It can be determined experimentally by measuring the time $(t_2 — t_1)$ that elapses in a given cycle interval $(P_1 \rightarrow P_2)$ under different constant temperatures (T). On the basis of the unit of the cycle interval and equation (1) the rate of progress of the active period at any constant temperature can then be obtained from equation

$$v(T) = 5\,\frac{h_{10}}{h_T}\ \text{p.u./h.} \tag{4}$$

in which h_{10} refers to the time that elapses in the cycle interval involved at a temperature of 10° and h_T, to the time lapse at temperature T.

Cycle intervals whose beginning and end lent themselves to accurate observations were chosen as objects for research. Furthermore, the method of treatment was so developed as to produce remarkably accurate h_T values at each of the experimental temperatures. Investigations were carried out on several tree species by measuring cycle intervals pertaining to the different parts of the active period. Utilizing the h_T-values obtained in this way, the rates of progress of the active period at the different constant temperatures employed in the investigations were calculated. The results obtained were combined into a graph (Fig. 11, p. 31) that shows the regression of the rate of progress of the active period on temperature. Since a curve could be fitted without difficulty to the dot cluster that demonstrates the rate of progress in the different parts of the active period in various tree species, it was concluded that the regression obtained had a wide range of application. The question of how wide the range is remains open.

This regression provides the answer or at least a significant part of the answer to the question of the operational principle of the physiological clock responsible for the synchronization of the annual cycles of the different tree species and of the annual cycles of trees of one and the same species within a biocoenosis.

The above results obtained under laboratory conditions were compared with corresponding results from nature by carrying out a few random tests. It was then proved that when the temperature was measured within a bud the correspondence between the phenomena occurring in nature and those taking place under laboratory conditions was satisfactory. The air temperature, early in the spring in particular, is considerably lower than the bud temperature and cannot, therefore, provide a satisfactory basis for the estimation of the rate of progress of the active period.

The regression of the rate of progress of the active period on temperature, the chief result of the present study, afforded an opportunity for a critical appraisal of the presently-used heat sum principles based more or less on the rule of thumb. On completion of the examination it was established that in the mid-part of the temperature range (9°— 28°C), for instance the d.d. and d.h. principles based on the 5°C threshold value produce results that correspond surprisingly well to the experimental values. Clarification and examination of these restrictions do not mean only criticism; on the contrary, when the restrictions are known, it will in many cases be more expedient to apply these simple and speedy methods instead of the more accurate ones which involve more work.

In late summer or early in the autumn, physiological processes occur, the fundamental function of which is apparently to improve the frost

hardiness of living cellular tissues. These processes make up a phenomenon referred to in this investigation as acclimation. It seems to be characteristic of these processes that the first low temperatures of the autumn have some effect on them inducing their onset or at least accelerating it.

In this respect, the acclimation processes differ from the phenomena included in the active period. However, it is a characteristic of the acclimation processes that, in their initial phase, before the temperature has dropped below 0°C, they progress more rapidly at high than at low temperatures. The rate of progress seems to depend on temperature in about the same way as in the active period. Seed and leaf abscission in the birch and accumulation of starch in the microspores of certain broad-leaved trees and its disappearance are examined as instances demonstrating acclimation.

Tiivistelmä

Käytännön metsätaloudessa on lämpösumman käyttö lämpötilan ja ajan yhteisvaikutuksen mittalukuna saamassa useita tärkeitä sovellutuksia. Tässä julkaisussa tehdään selkoa niistä tutkimuksista, jolle lämpösumman käytön teoreettinen pohja rakentuu. Nämä tutkimukset ovat samalla, jossakin määrin yllättäen, valaisseet metsäpuiden vuotuiseen syklukseen liittyvää, yleensä myöhäissyksyllä tapahtuvaa puiden talveentumistapahtumaa. Tätä ilmiötä, jolla käytännön sovellutuksena on ehkä ennen kaikkea merkitystä taimien ja siementen käsittelyssä, valaistaan luonnossa tehtyihin mittauksiin perustuen.

Tutkimus lähtee siitä toteamuksesta, että metsäkasvillisuuden, erityisesti sen puuston, vuotuisen kehityksen syklus on erinomaisen täsmällisesti synkronisoitu puuston eri komponenttien kesken. Nousee kysymys, mikä on sen fysiologisen kellon periaate, joka vastaa tästä synkronisoinnista. Tämä on tutkimuksen keskeinen ongelma.

Tutkimukseen syvennyttyä on käynyt ilmeiseksi, että ongelman ratkaisu tuskin on mahdollista muuten kuin tähtäämällä koko vuotuisen sykluksen toimintaperiaatetta koskevan mallin asettamiseen. Syklus jaetaan aluksi karkeasti kahteen osaan: aktiiviin periodiin ja talvidormansiin. Käsillä olevassa tutkimuksessa rajoitutaan vain aktiiviin periodiin, mutta sen tutkiminen on tapahtunut kiinteässä yhteydessä talvidormansin mallin rakentamiseen.

Tutkimus lähtee siitä jo aikaisemmasta tuloksesta, että aktiivin periodin eteneminen on nähtävästi jokseenkin yksinomaisesti vain ajan ja lämpötilan valvonnassa.

Tällöin konstantissa lämpötilassa on voimassa kaava:

$$P_1 \rightarrow P_2 = v\,(T)\,(t_2 - t_1) \tag{1}$$

jossa $P_1 \rightarrow P_2$ tarkoittaa ajankohtien t_1 ja t_2 välistä syklusväliä, T vakiolämpötilaa ja v sykluksen etenemisnopeutta. Milloin lämpötila jatkuvasti vaihtelee, kuten luonnon oloissa, kaava saa muodon

$$P_1 \rightarrow P_2 = \int_{t_1}^{t_2} v\,(T\,(t))\,dt \tag{2}$$

Tämä voidaan käytännön laskuja, esim. ATK-ohjelmia varten approksimoida muotoon

$$(3) \qquad P_1 \rightarrow P_2 = \sum_{i=1}^{n} v\,(Ti)\, t_i$$

jossa i on i:nnes lämpötilanmittaus, kun P_1:stä P_2:een kulunut aika on jaettu n:ään yhtäsuureen osaan. Kaavoissa 1—3 v on ainoa tuntematon. Se on määritetty kokeellisesti mittaamalla tiettyyn syklusväliin ($P_1 \rightarrow P_2$) erilaisissa vakiolämpötiloissa (T) kulunut aika (t_2—t_1). Syklusvälin yksikön määritelmän ja kaavan (1) perusteella aktiivin periodin etenemisnopeus missä tahansa vakiolämpötilassa voidaan laskea tämän jälkeen kaavasta

$$(4) \qquad v\,(T) = 5\,\frac{h_{10}}{h_T}\ \text{p.u./t}$$

missä h_{10} tarkoittaa sitä aikaa, mikä kyseiseen syklusväliin kuluu + 10° lämpötilassa ja h_T sitä aikaa, joka kuluu lämpötilassa T.

Tutkimuksen kohteeksi otettiin sellaisia syklusvälejä, joiden alku- ja loppuhetkestä voidaan tehdä hyvin tarkkoja havaintoja. Lisäksi havaintomateriaalin käsittely kehitettiin sellaiseksi, että kussakin koelämpötilassa saatiin h_T:lle huomattavan suuri tarkkuus. Tutkimuksia suoritettiin useilla puulajeilla ja aktiivin periodin eri osiin kuuluvia syklusvälejä mitaten. Näin saatuja h_T-arvoja käyttäen laskettiin aktiivin periodin etenemisnopeus niissä vakiolämpötiloissa, joissa tutkimuksia oli tehty. Saadut tulokset yhdistettiin diagrammiksi (kuva 11, s. 31), joka esittää aktiivin periodin etenemisnopeuden ja lämpötilan regression. Koska eri puulajeihin ja aktiivin periodin eri osiin kuuluviin syklusväleihin perustuvat nopeudet voitiin pistediagrammille väkivaltaa tekemättä tasoittaa yhdellä käyrällä, pääteltiin, että saadulla regressiolla on laajahko sovellutus — miten laaja, jää tässä tutkimuksessa avoimeksi.

Tämä regressio on vastaus — tai ainakin tärkeä osavastaus, kysymykseen, mikä on toimintaperiaate siinä fysiologisessa kellossa, joka vastaa eri puuyksilöiden vuotuisten syklusten synkronisoinnista tietyn eloyhteisön sisällä.

Koska edellä selostetut tutkimustulokset oli saavutettu suorittamalla kokeita laboratorio-oloissa, tehtiin muutamin pistokokein vertailuja vastaaviin tapahtumiin luonnossa. Tällöin osoittautui, että mittaamalla luonnossa lämpötila silmuissa vastaavaisuus oli tyydyttävä. Varsinkin varhaiskeväällä ilman lämpötila on huomattavasti alhaisempi kuin silmulämpötila eikä sen vuoksi voi antaa tyydyttävää kuvaa aktiivin periodin etenemisnopeudesta.

Tutkimuksen päätulos, aktiivin periodin etenemisnopeuden ja lämpötilan regressio, tarjoaa mahdollisuuden kriitillisesti tarkastella käytännössä olevia,

enemmän tai vähemmän peukalotuntumaan nojaavia lämpösummamenetelmiä. Tällainen tarkastelu suoritetaan, ja todetaan, että keskeisillä lämpötilaalueilla (+9°—+28°C) esim. +5° kynnysarvoon perustuva d.d.-periaate ja d.h.-periaate antavat yllättävän hyvin kokeellisia tuloksia vastaavia arvoja.

Kesän lähestyessä loppua ja varhaissyksyllä tapahtuu fysiologisia prosesseja, joiden perimmäisenä tarkoituksena ilmeisesti on lisätä elävien solukoiden talvenkestävyyttä. Näistä käytetään yhteisesti nimeä talveentuminen. Niille on ominaista, että syksyn ensi alhaisilla lämpötiloilla näyttää olevan niiden liikkeelle lähtöä indusoiva tai ainakin niitä kiihdyttävä vaikutus.

Tässä talveentumisilmiöt eroavat aktiivin periodin ilmiöistä. Talveentumisilmiöille on kuitenkin ominaista, että ne ensimmäisessä vaiheessaan, ennen kuin lämpötila on laskenut 0°C alapuolelle, edistyvät nopeimmin korkeissa kuin alhaisissa lämpötiloissa. Etenemisnopeus näyttää riippuvan lämpötilasta likimäärin samalla tavoin kuin aktiivissa periodissa. Talveentumista havainnollistavina esimerkkeinä tarkastellaan koivun siementen ja lehtien varisemista sekä tärkkelyksen kerääntymistä eräiden lehtipuiden mikrosporeihin ja sen häviämistä.

Literature Cited

Alleweldt, G. 1968. The role of auxin in the dormancy of buds of woody plants. Transport of plant hormones, 425—449. Amsterdam.

Andersson, Enar, Inger Ekberg and Gösta Eriksson. 1969. A summary of meiotic investigations in conifers. Studia forestalia Suecica 70.

Arzt, Theodor and Wilhelm Ludwig. 1949. Alte Probleme der Phänologie in neuer Beleuchtung. Naturw. Rundschau 2, 450—459.

Barner, H. and H. Christiansen. 1960. The formation of pollen, the pollination mechanism, and the determination of the most favorable time for controlled pollinations in Larix. Silvae genetica 9, 1—11.

Burckhardt, Fr. 1860. Über die Bestimmung des Vegetationsnullpunktes. Verh. d. Naturf. Gesellsch. in Basel 2, 1860, 47—62.

Candolle, M. A. de. 1865. De la germination sous des degrés divers de température constante. Arch. d. sc. phys. et naturelles. Nov. pér. 24, 243—282.

Carns, Harry R. 1966. Abscission and its control. Annual rew. of plant physiology 17, 295—314.

Chira, Eugen. 1964. Vplyv teploty na priebeh meiózy pel'ových materských buniek Taxus baccata L. Biológia 19, 235—243.

Christiansen, H. 1960. On the effect of low temperature on meiosis and pollen fertility in Larix decidua Mill. Silvae genetica 9, 72—78.

Dietrichson, J. 1964. The provenance problem illustrated by studies of growth-rhythm and climate. (Orig. Norwegian with English summary). Meddel. Det Norske skogforsøksvesen 71, 499—656.

Dingler, H. 1902. Zum herbstlichen Blattfall. Forstw. Centralbl. 24, 195—204.

Dormling, I., Å. Gustafsson and D. von Wettstein. 1968. The experimental control of the life cycle in Picea abies (L.) Karst. I. Some basic experiments on the vegetative cycle. Silvae genetica 17, 44—64.

Ekberg, Inger, G. Eriksson, N. Kartel and Zuzana Šulíková. 1967. The meiotic development in male aspen. Studia forestalia Suecica 58.

Ekberg, Inger, G. Eriksson, and Zuzana Šulíková. 1968. Meiosis and pollen formation in Larix. Hereditas 59, 427—438.

Ekberg, Inger and G. Eriksson. 1967. Development and fertility of pollen in three species of Larix. Hereditas 57, 303—311.

Eriksson, G. 1968. Temperature response of pollen mother cells in Larix and its importance for pollen formation. Studia forestalia Suecica 63.

Falconer, D.S. 1964. Introduction to quantitative genetics. Edinburgh and London.

Hagner, Mats. 1970a. The intra-provenance correlation between annual rhythm and growth of single trees of Pinus silvestris L. Studia forestalia suecica 82.

—»— 1970b. Experimental assessment of climatic adaptation of pine (Orig. Swedish). Umeå University Public. Umeå.

Herbst, W. and N. Weger. 1940. Zur Physiologie des Fruchtens bei den Obstgehölzen. Forschungsdienst 9, 518—525.

Holzer, K. 1966. Die Vererbung von physiologischen und morphologischen Eigenschaften der Fichte. 1. Sämlingsuntersuchungen. Inheritance of physiological and morphological characteristics in Norway spruce. 1. Seedling tests. Mitt. Forstl. Bundes-Versuchsanstalt Mariabrunn 71.

Kolkki, Osmo. 1966. Tables and maps of temperature in Finland during 1931—1960. Meteorolog. Yearbook of Finland 65, 1a.

Langlet, O. 1936. Studien über die physiologische Variabilität der Kiefer und deren Zusammenhang mit dem Klima. Beiträge zur Kenntnis der Ökotypen von Pinus silvestris L. (Orig. Swedish with German summary). Medd. Statens skogförsöksanstalt 29, 219—470.

Leike, Heinz. 1965. Neuere Ergebnisse über die Ruheperiode (Dormancy) der Gehölzknospen. Wiss. Zeitschr. Univ. Rostock 14, 475—492.

Lessmann, H. 1948. Eine Methode zur Voraussage des Blühbeginnes bei den Obstgehölzen. Wetter und Klima 56.

Linsser, G. 1867. Die periodischen Erscheinungen des Pflanzenlebens in ihrem Verhältnis zu den Wärmeerscheinungen. Mém. de l'Acad. imp. d. sc. de St. Pétersbourg XI, Nr. 7, 1—44.

Lomakka, Lennart. 1958. Norra Fennoskandias jordbruk. Del. I. Nordisk Jordbrugsforskning 40, 131—351.

Magnesen, S. 1969. Ecological experiments regarding growth termination in seedlings of Norway spruce. 1. Effect of daylength and temperature conditions during growth season. (Orig. in Norwegian with English summary). Medd. Vestlandets forstlige forsøksstation 48.

—»— 1971. Ecological experiments regarding growth termination in seedlings of Norway spruce. 2. Effect of autumn temperature and periods of low night temperature (Orig. Norwegian with English summary). Medd. Vestl. forstl. forsøksst. 51, 223—269.

Mohl, Hugo. v. 1860. Ueber die anatomischen Veränderungen des Blattgelenkes, welche das Abfallen der Blätter herbeiführen. Bot. Ztg 18, 1—7, 9—17.

Molisch, H. 1916. Pflanzenphysiologie als Theorie der Gärtnerei. Jena.

Mork, E. 1941. Om sambandet mellom temperatur og vekst. Undersøkelser av de daglige variasjoner i granens høydetilvekst. — Medd. Det Norske skogforsøksvesen 8 (27), 1—89.

—»— 1960. On the relationship between temperature, leading shoot increment and the growth and lignification of the annual ring in Norway spruce (Picea abies) (L.) (Karst.) (Orig. Norwegian with English summary). Medd. Det Norske skogforsøksvesen 56, 225—261.

—»— 1968. Ecological investigations in the mountain forest at Hirkjølen Experimental area (Orig. Norwegian with English summary). Medd. det Norske skogforsøksvesen 93, 463—614.

Nienstaedt, H. 1966. Dormancy and dormancy release in White spruce. Forest science 12, 374—384.

Oettingen, A. J. 1882. Phänologie der Dorpater Lignosen, ein Beitrag zur Kritik phänologischer Beobachtungs- und Berechnungsmethoden. Archiv. für die Naturkunde Liv-, Est- und Kurlands 8.

Owens, John N. 1968. Initiation and development of leaves in Douglasfir. Canad. Jour. of Botany 46, 271—278.

Perry, Thomas O. 1971. Dormancy of trees in winter. Photoperiod is only one of the variables which interact to control leaffall and other dormancy phenomina. Science 71, 29—36.

Réaumur, M. de. 1735. Observations du thérmometre, faites à Paris pendant l'année 1735. Mém. d. l'Acad. roy. sc. Paris, 737—754.

Roback, H. 1957. On the connection between day length and termination of the annual growth period in seedlings of some conifers of interest to norwegian forestry. (Orig. Norwegian with English summary). Medd. Vestlandets forst. forsøksstasjon 31, 1—62.

—»— 1962. New nursery experiments regarding the connection between summer day length and termination of growth in seedlings of Norway spruce and Douglas fir in their first growth year. (Orig. Norwegian with English summary). Medd. Vestlandets forstl. forsøksstasjon 36, 199—246.

Roche, L. 1969. A genecological study of the genus Picea in British Columbia. New Phytol. 68, 505—554.

—»— 1970. The effect of pfotoperiod on vegetative growth and generative development in coniferous tree species. Proc. IUFRO Section 22 Working group meeting Finland.

Romberger, J. A. 1963. Meristems, growth, and development in woody plants. U.S. Dept. Agr., Forest Service, Tech. bull. No. 1293.

—»— 1969. Apical meristems of trees. Why we study them. Agr. science rev. 7, 1—10.

Romberger, J. A., R J. Varnell, and C. A. Tabor. 1970. Culture of apical meristems and embryonic shoots of Picea abies — approach and techniques. U.S. Dept. Agr. For. Serv. Tech. bull. No. 1409.

Sakai, A. and S. Okada. 1971. Freezing resistance of conifers. Silvae genetica 20, 91—97.

Sarvas, R. 1962. Investigations on the flowering and seed crop of Pinus silvestris. Comm. Inst. forest. fenn. 53.

—»— 1967. The annual period of development of forest trees. Proceed. Finnish academy of science and letters 1965.

—»— 1968. Investigations on the flowering and seed crop of Picea Abies. Comm. Inst. forest. fenn. 67.

—»— 1970a. Establishment and registration of seed orchards. Folia forestalia 89.

—»— 1970b. The annual developmental cycle of forest trees. Proceed. IUFRO Section 22, Working group meeting on the sexual reproduction of forest trees Finland 1970.

Schnelle, Fritz. 1955. Pflanzen-Phänologie. Leipzig.

Schüepp, Walter. 1950. Phänometrisches Experiment über die »Winterruhe» einiger Pflanzen. Wetter und Leben 2, 205—211.

Sinnot, E. W., L. C. Dunn and T. Dobzhansky. 1958. Principles of genetics. New York, Toronto, London.

Vaartaja, O. 1959. Evidence of photoperiodic ecotypes in trees. Ecological monographs 29, 91—111.

—»— 1960. Ecotypic variation of photoperiodic response in trees especially in two Populus species. Forest science 6, 200—206.

Wareing, P. F. 1950. Growth studies in woody species I. Photoperiodism in first-year seedlings of Pinus silvestris. Physiologia plantarum 3, 258—276.

Wareing, P. F. and M. Black. 1958. Photoperiodism in seeds and seedlings of woody species. K. V. Thimann. The physiology of forest trees. The Ronald Press Co. New York, 539—556.

Weger, N., W. Herbst and C. F. Rudloff. 1940. Witterung und Phänologie der Blühphase des Birnbaumes. Reichsamt für Wetterdienst, Wissenschaftliche Abhandlungen 7, 1—28.

Weiser, C. J. 1970. Cold resistance and injury in woody plants. Science 169, 1 269—1 278.

FLIGHT PERIOD AND BROOD EMERGENCE IN *TRYPODENDRON LINEATUM* (OLIV.) (COL., SCOLYTIDAE) IN THE NORDIC COUNTRIES

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PREFACE

The present study is the result of cooperation between forest entomologists of the Nordic Countries. The investigations have been sponsored by the following institutions:

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1. INTRODUCTION

The ambrosia beetle, *Trypodendron lineatum* (Oliv.) is a widespread species, found over most of the northern coniferous zone in Europe, Asia and North America (Escherich 1923, Hadorn 1933). This bark beetle is polyphagous, feeding on many species of conifer (Escherich 1923, Saalas 1923, Prebble & Graham 1957, Johnson 1958, Capecki 1967). In virgin forests, *T. lineatum* lives at the bases of standing trees that have just died or in fallen trees. Now that timber is mainly stored unbarked, *T. lineatum* has become a timber pest of considerable economic significance (Fisher et al. 1953, 1954, McMullen 1956, Wood 1957, Bletchly & White 1962, Rudinsky & Daterman 1964 a, Schindler 1967). The felling date is found to be of great significance in determining the susceptibility of timber to damage by *T. lineatum* (Bletchly 1961, Chapman 1961, Austarå & Saether 1965, Dyer & Chapman 1965, Dyer 1967, Christiansen & Saether 1968). The orientation of this bark beetle to suitable breeding material has been studied extensively over the past few years (e.g. Rudinsky & Daterman 1964 b, Chapman 1966, Rudinsky 1966, Castek et al. 1967, Francia & Graham 1967, Borden et al. 1968, Graham 1968, Borden & Slater 1969, Schneider & Rudinsky 1969, Nijholt 1970, Moeck 1970).

Although the biology of *T. lineatum* has been studied in considerable detail elsewhere (e.g. Hadorn 1933, Novak 1960), the Nordic literature on forest entomology provides relatively little information on the life pattern of this species (Saalas 1917, 1919, Bakke 1960, Rummukainen 1964, Pulliainen 1965, Löyttyniemi 1967). Because the Nordic countries have also suffered from the increased damage done by *T. lineatum* in recent years, forest entomologists in these countries decided to investigate the flight, attack and emergence of this bark beetle simultaneously in various parts of the North.

2. MATERIALS AND METHODS

The experiments reported here were conducted in Denmark, Finland, Norway and Sweden in the years 1968—1969. The names and geographical locations of the experimental sites are shown in Fig. 1.

At each site, spruces (*Picea abies* (L.) Karst.) (in Gribskov, Denmark, also some *Picea sitchensis* (Bong.) Carr.) were felled in December (1967, 1968) and cut into logs about 3 m long and from 10 to 30 cm in diameter. In March of the following year (before the last snow had melted) at least 10 logs were placed in stacks of one layer. The stacks were generally placed in a spruce forest 20 to 30 m from the edge of the stand, and at Frøslev, Denmark, on the edge of a small glade. On the four sides of each lot were placed window flight traps (60 cm by 50 cm plexiglass) (Fig. 2, cf. Chapman & Kinghorn 1955). The troughs of the window traps were made of galvanized zinc or plastic. A wetting agent was added to the water in the troughs so that insects falling into the water sank to the bottom and were unable to climb out of the trough. At each locality, the traps were inspected and emptied every third day (in Denmark twice a week) at the same time of day. Trap inspection was started immediately after the snow had melted and continued at least until late October. Insects collected in traps were preserved in 70 % alcohol for laboratory investigation.

In Denmark and Finland when the window traps were emptied, a numbered plastic tag was attached beside each new entry hole. Entry holes were counted in three section 50 cm long at each experimental site until early July. Because the logs were also attacked by a great number of other scolytids, particularly *Hylurgops palliatus* Gyll., (cf. Subansenee 1971) the sections in Finland were sawn off from the logs in October and taken to the laboratory for confirmation of the species responsible for the marked holes.

To study the emergence of the brood, three logs 1 to 1.5 m long attacked by *T. lineatum* were suspended in nylon gauze bags in early July so that the lower ends of the logs were about 0.5—1.0 m above the ground. The lower ends of the bags were attached to funnels and collecting bottles half filled with ethylene glycol (Fig. 2). The bottles were emptied at least once a week until late October and the beetles collected were preserved in 70 % alcohol.

For temperature measurements, a meteorological screen was set up on each experimental site 2 m above the ground. Inside the screen were a thermograph and a precision thermometer (Fig. 2). Temperature was always noted from the latter on arrival at the experimental site. In Denmark and Sweden temperature observations were made at climatological stations located in the vicinity of the experimental sites (Rude Skov some 20 km

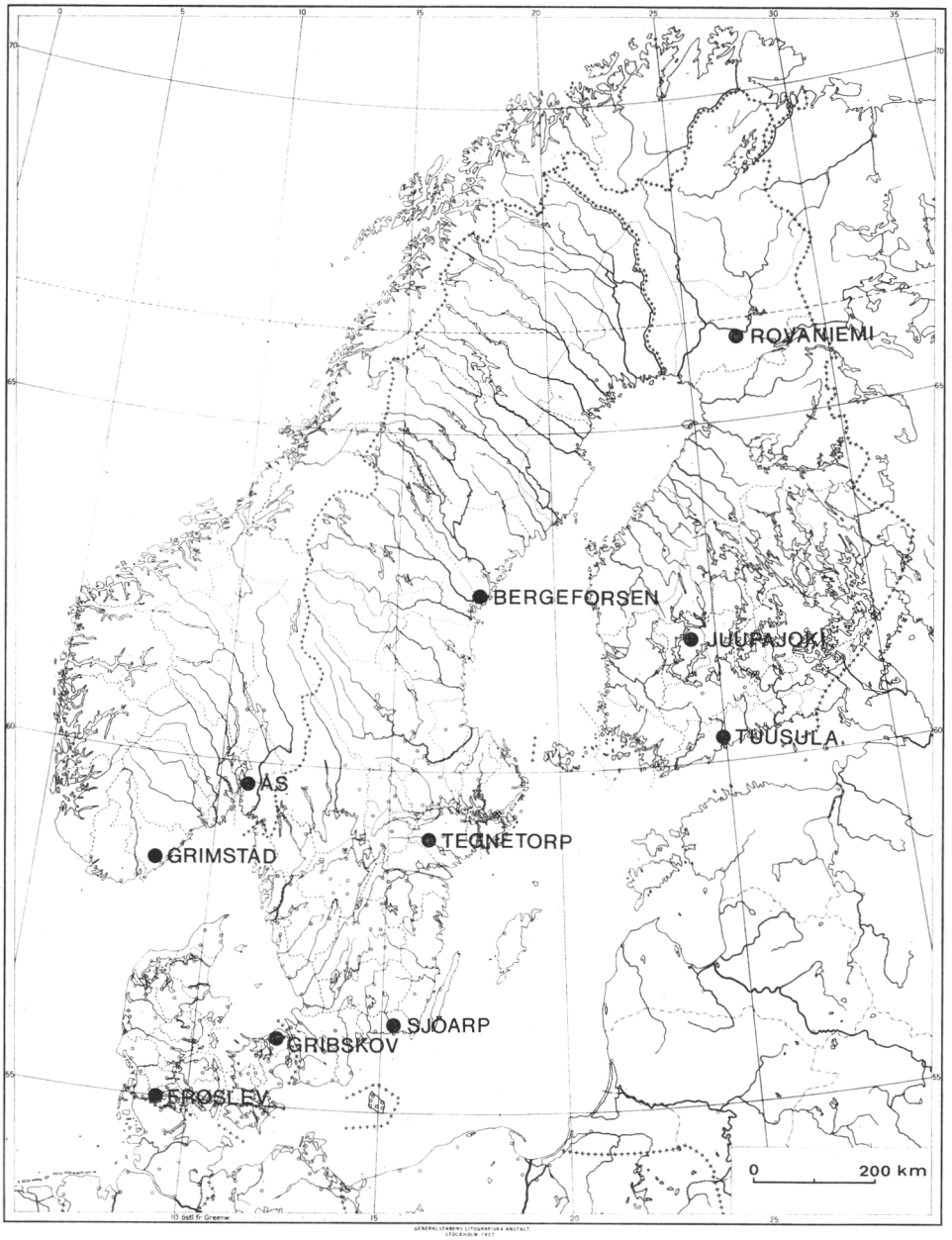

Fig. 1. Situation of the experimental sites in the Nordic Countries.

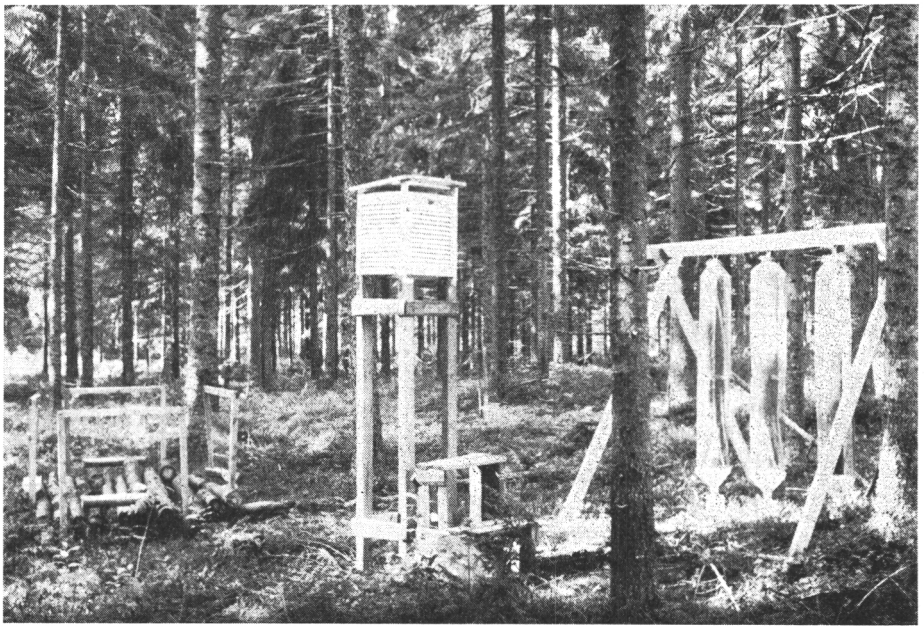

Fig. 2. An experimental site at Tuusula (Finland) in 1969. Left: window flight traps; centre: meteorological screen; right: emergence bag traps. — Photo E. Annila.

south of Gribskov, Rens some 20 km west of Frøslev, Bredåkra close to Sjöarp, Simonstorp close to Tegnetorp, Sundsvall close to Bergeforsen).

In the laboratory *Trypodendron* beetles were separated from the insects collected in the field. The beetles from part of the material collected in Finland, Sweden and Denmark were sexed. One of the sex-determining features was among others the shape of the front of the head (cf. e.g. R e i t t e r 1916): in the female the head is convex and in the male concave.

3. RESULTS

3.1. Flight

Figs. 3 and 4 show the numbers of *Trypodendron lineatum* collected during the flight period with window traps and the daily temperature maxima 2 m above the ground. In 1968, initial spring flight took place in Denmark and southern Sweden at about the same time in mid-April, in southern Norway about five days later, in southern Finland about one week and in central Finland about two weeks later. In 1969, the initial spring flight took place in Denmark and southern Norway 10 days later than in the previous

year. In central Sweden, the corresponding difference was 20 days and in southern Finland 7 days. In northern Finland, the initial spring flight took place more than one month later than in Denmark.

Although the flight period may be considered to have continued until late June, most of the beetles were on the move in the early part of their flight period, as the following table shows (percentages are based on the numbers of beetles collected by the end of June):

	1968				1969			
	30. IV	15. V	31. V	15. VI	30. IV	15. V	31. V	15. VI
	percentages							
Frøslev D	85.9	86.0	90.9	96.5	42.7	91.4	93.5	99.0
Gribskov D	93.8	93.9	94.7	99.6	0.8	62.8	87.6	93.1
Sjöarp S	74.4	91.0	94.1	97.9	—	—	—	—
Grimstad N	—	—	—	—	0.0	0.0	94.8	98.6
Tegnetorp S	87.4	91.7	95.0	99.0	0.0	54.4	87.5	96.3
Ås N	69.9	76.8	95.4	99.8	—	—	—	—
Tuusula F	32.4	71.7	95.9	99.0	0.0	91.2	97.6	99.1
Juupajoki F	0.0	56.2	95.8	99.1	—	—	—	—
Bergeforsen S	—	—	—	—	0.0	0.0	93.5	99.5
Rovaniemi F	—	—	—	—	0.0	0.0	0.0	77.6

D = Denmark, F = Finland, N = Norway, S = Sweden

In 1968, most of the beetles began their flight in April in Denmark, southern Norway and southern as well as central Sweden. In southern Finland, flight activity was largely over by mid-May and in central Finland by the end of the month. According to Schindler (1969), *Trypodendron* had its flight period in the German Lowlands in mid-March and in the Highlands in early April.

Although flight activity began somewhat later the following year, most of the beetles had completed their flight in Denmark and southern Finland by mid-May. At the other experimental sites, too, flight periods were practically over by the end of May, except at Rovaniemi, where flight activity did not start until the beginning of June.

To summarize, the spring flight period of *T. lineatum* was essentially over after the first two weeks but was extended in some localities to as much as two months. Flying beetles were caught in small numbers throughout the summer, and another clear, although less prominent, peak occurred towards the end of the summer. This second peak was obviously due to a new wave of attack by parent beetles seeking suitable trees in which to establish a second brood.

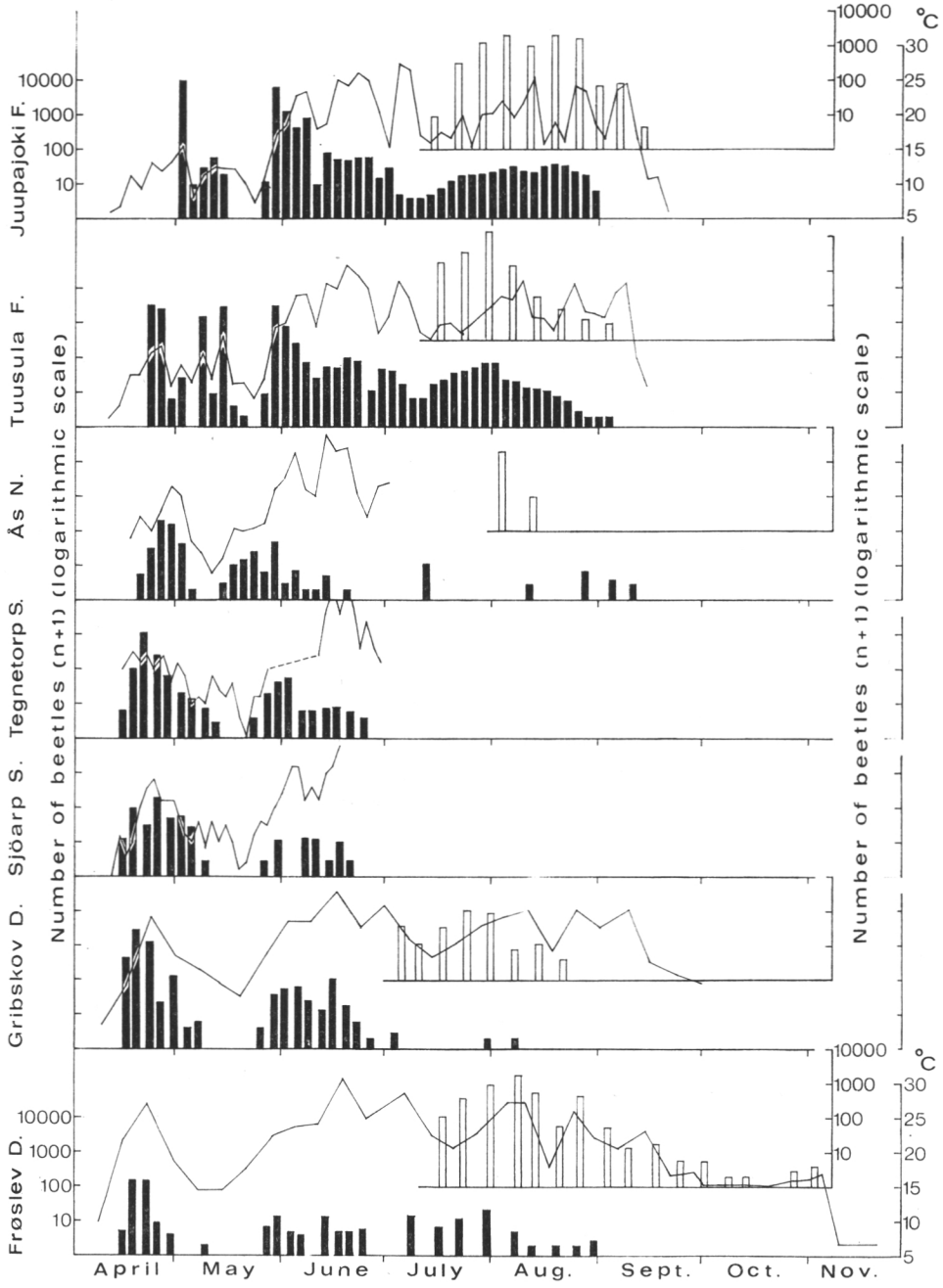

Fig. 3. Seasonal flight and emergence of *Trypodendron lineatum* in 1968. Black columns = beetles collected in window flight traps, white columns = beetles collected in emergence bag traps, solid line = maximum air temperature, D = Denmark, F = Finland, N = Norway, S = Sweden.

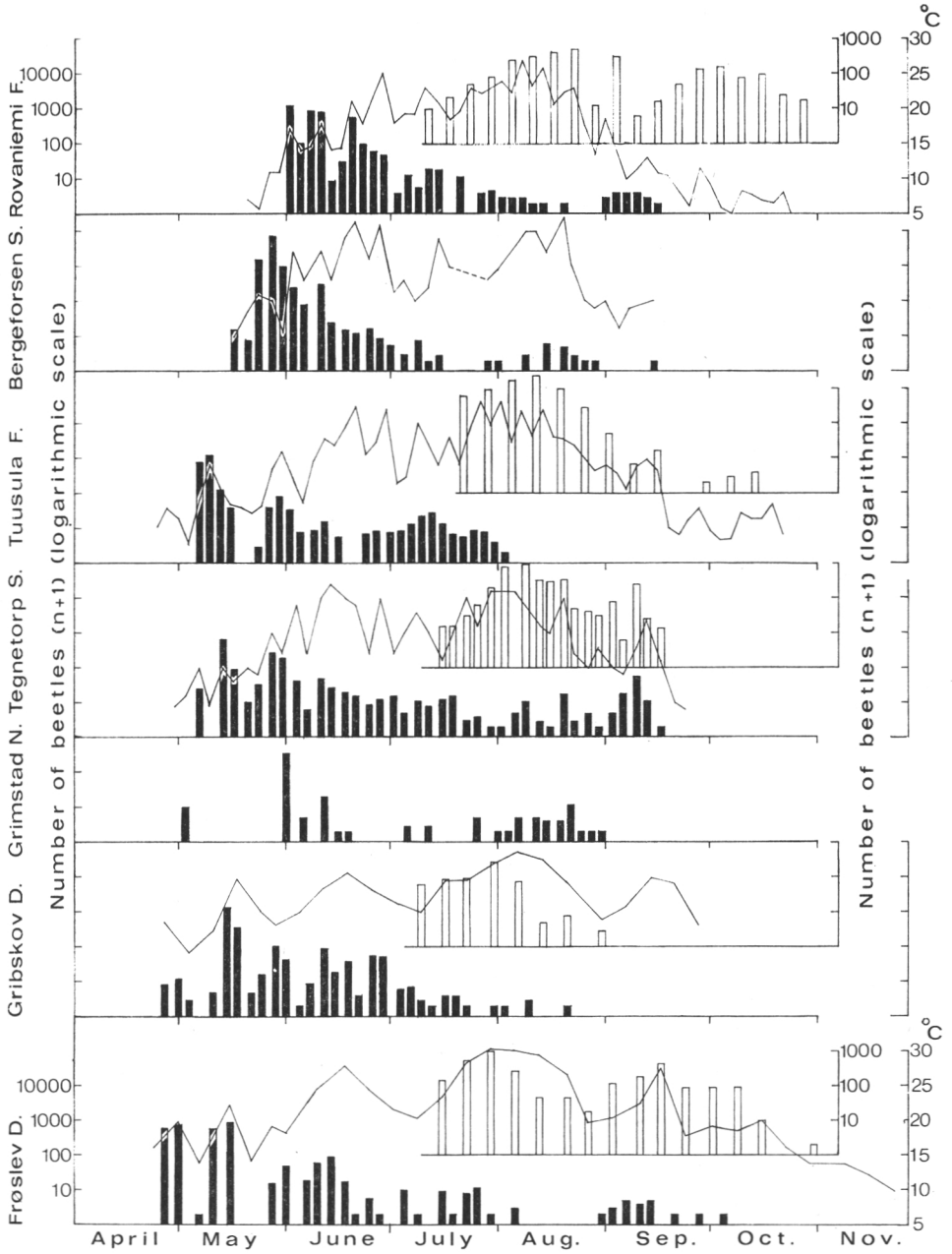

Fig. 4. Seasonal flight and emergence of *Trypodendron lineatum* in 1969. For explanations, see the legend to Fig. 3.

3.2 Weather situation during flight

T. lineatum does not begin its flight activity until a certain threshold temperature has been reached (cf. e.g. H a d o r n 1933, S c h w e r d t f e g e r 1970). Because the present investigation is concerned with the flight pattern of this bark beetle over a large, fairly uniform area, it is worth studying the weather conditions prevailing in Northern Europe during the flight period. *T. lineatum* overwinters under the snow (H a d o r n 1933), and flight is possible only after the snow has melted. The following table shows the dates at which the snow cover disappeared at the different experimental sites in 1968 and 1969. The information was obtained from the Weather Bureaus of the countries concerned. (Information from Denmark is lacking, because there is rarely a continuous snow cover there throughout the winter.)

	1968	1969
Sjöarp S	26.III	—
Grimstad N	—	29.IV
Tegnetorp S	29.III	24.IV
Ås N	11.IV	—
Tuusula F	18.IV	30.IV
Juupajoki F	22.IV	—
Bergeforsen S	—	9.V
Rovaniemi F	—	25.V

On 10 April 1968 a high pressure centre over the North Sea was gradually moving northeast. By 15 April it had reached the southern Baltic and on 17 April the high pressure centre extended from Denmark across the Baltic countries to the White Sea. The high pressure remained largely stationary until late April. Low pressures moved past in the north, causing relatively cool and unstable weather in the northern and central parts of Scandinavia. Under high pressure, day temperatures rose to 15—20°C around mid-April in Denmark and the southern parts of Scandinavia. Southern and central Finland were in a high pressure ridge and the temperature rose above 15°C for the first time on 21 April in Tuusula and 30 April in Juupajoki. *T. lineatum* mostly flew in Denmark and the south of Scandinavia during this anticyclone, as Fig. 3 shows. In southern and central Finland, on the other hand, flights began during that period but the proportion of beetles in flight was low.

In early May, low pressures moved across the southern and central parts of Scandinavia, during which time temperatures remained relatively low. The effect of cyclones on flight patterns is shown very clearly by the diagrams. In late May, a strong high pressure again prevailed in Northern Europe, during which considerable flight activity still occurred in southern and central Finland.

In 1969, in the latter part of April, low pressures moved across southern and central Scandinavia, but towards the end of the month a high pressure, extending from Russia to Central Europe, pushed temperatures above 15°C in Denmark. At this time Frøslev (Denmark) was the only site where flight activity was considerable, but even there the proportion of beetles in flight did not exceed 50 per cent of the number of beetles trapped during the entire flight period. It may be noted that at Rovaniemi, in northern Finland, the snow cover was 80 cm deep in late April. Temperatures remained fairly low until early May, when a weak high pressure was over the Baltic. Its effects at Frøslev, Gribskov, Tegnetorp and Tuusula are clearly visible in the diagrams. On 14—20 May, low pressures moved across the central parts of Scandinavia but in their wake came a high pressure from the Atlantic with its center in the Gulf of Bothnia on 23—24 May. The high pressure had a remarkably strong influence on *Trypodendron* flight activity in Bergeforsen. In northern Finland, flights did not begin until early June, when a high pressure prevailed in Northern Scandinavia.

3.3 Emergence

Figs. 3 and 4 show the numbers of *Trypodendron lineatum* collected in emergence traps. Emergence took place immediately after the logs were hung up in the rack, but was most abundant at each experimental site in late July and early August. In September and October, emergence was fairly low. The year 1969, however, was different; at Frøslev, in Denmark, the second peak of emergence occurred in mid-September and at Rovaniemi, in northern Finland, emergence was also abundant in late September and early October. In the latter locality, the first peak (July) may have included a great number of parent beetles. It is interesting to note that toward the end of the summer, a relatively large number of beetles were caught in the window traps just at the time of active emergence (Frøslev 1968, 1969, Tuusula and Juupajoki 1968, Tegnetorp 1968). Thus it seems obvious that some of the beetles caught in the window traps were newly emerged. It is noteworthy that on all experimental sites, emergence took place essentially at the same time, despite considerable differences in flight periods.

3.4. Attack

A very interesting and important factor from the angle of *Trypodendron lineatum* control is the time of attack and its relation to the flight period. Fig. 5 shows the number of entry holes in the logs on some experimental sites. A comparison of Figs. 3, 4 and 5 will show that the beetles started boring into the wood immediately after flight. The attack period was clearly

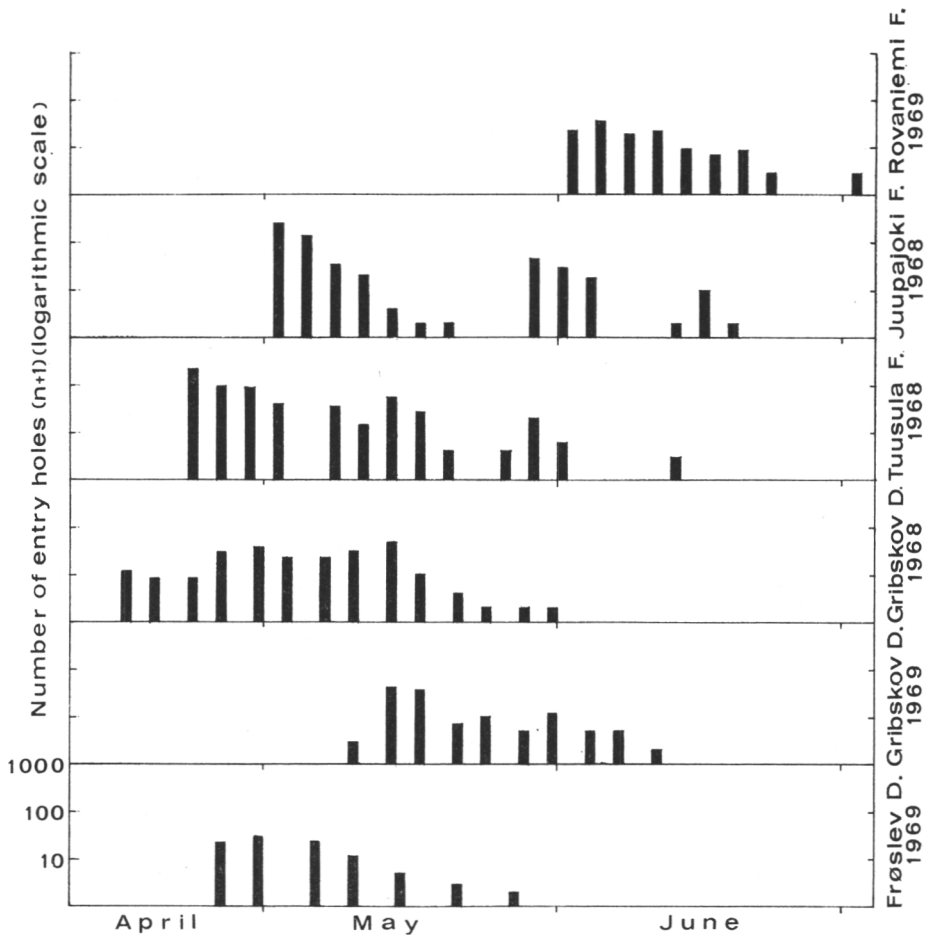

Fig. 5. Seasonal attack of *Trypodendron lineatum*.

shorter than the flight period. As noted before, flights continued to some extent for at least two months. On the other hand, attack may be considered, for all practical purposes, to have occurred only during one month after the start of flight activity.

3.5. Sex ratio

Figs. 6 and 7 show sex ratios during flight and emergence. Although the sex ratios seem to vary considerably, they were always very close to the average percentage recorded, when the beetles were abundant.

Tables 1 and 2 give a summary of the sex ratios of beetles collected during flight and emergence. It is interesting to note that during both

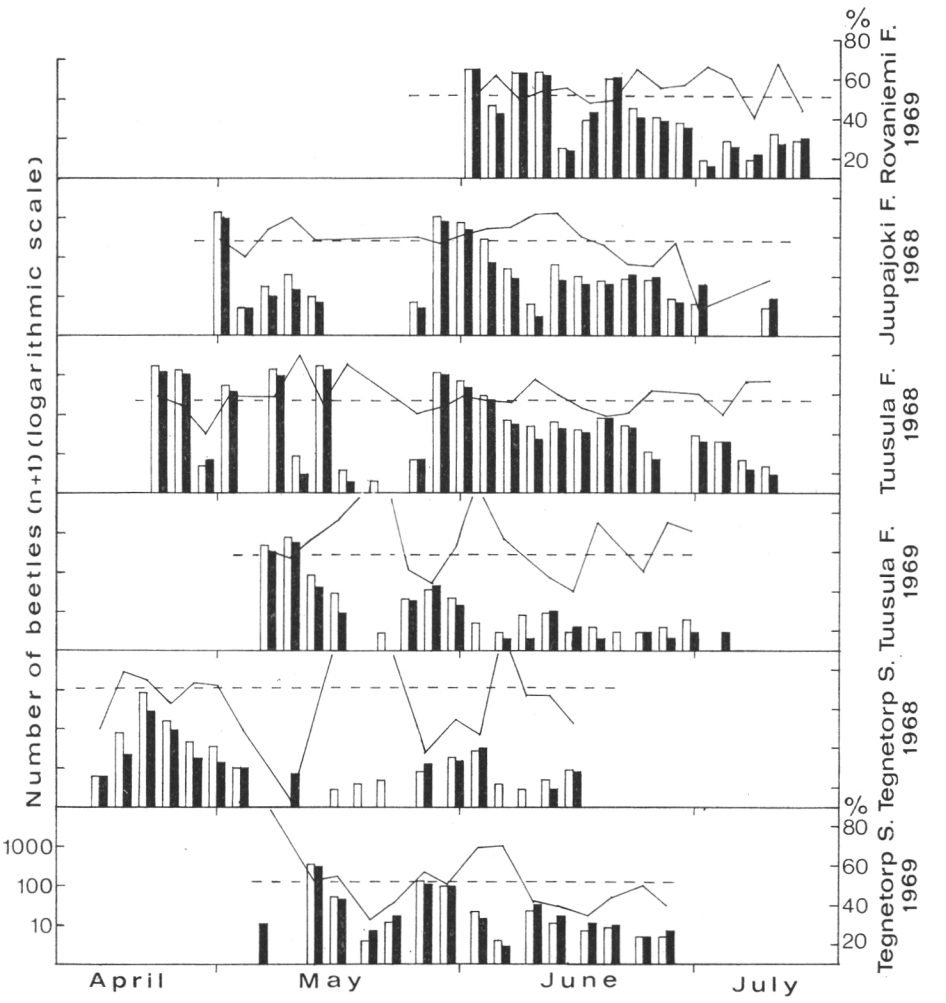

Fig. 6. The sex ratios in samples of *Trypodendron lineatum* collected in window flight traps. White columns — males, black columns = females, solid line = percentage of males, dashed line = average percentage of males.

flight and emergence, the males, almost without exception, significantly outnumbered the females. Rovaniemi was the only locality where females were slightly more abundant than males during emergence in 1969. Moreover, it may be noted that the proportion of males was clearly greater during flight than during emergence. Samples collected with window traps in Frøslev, Denmark, in 1968 during flight contained 216 males and 202 females. The difference is not statistically significant ($\chi^2 = 0.468$). From the material collected during emergence on the same site 665 beetles were sexed, of

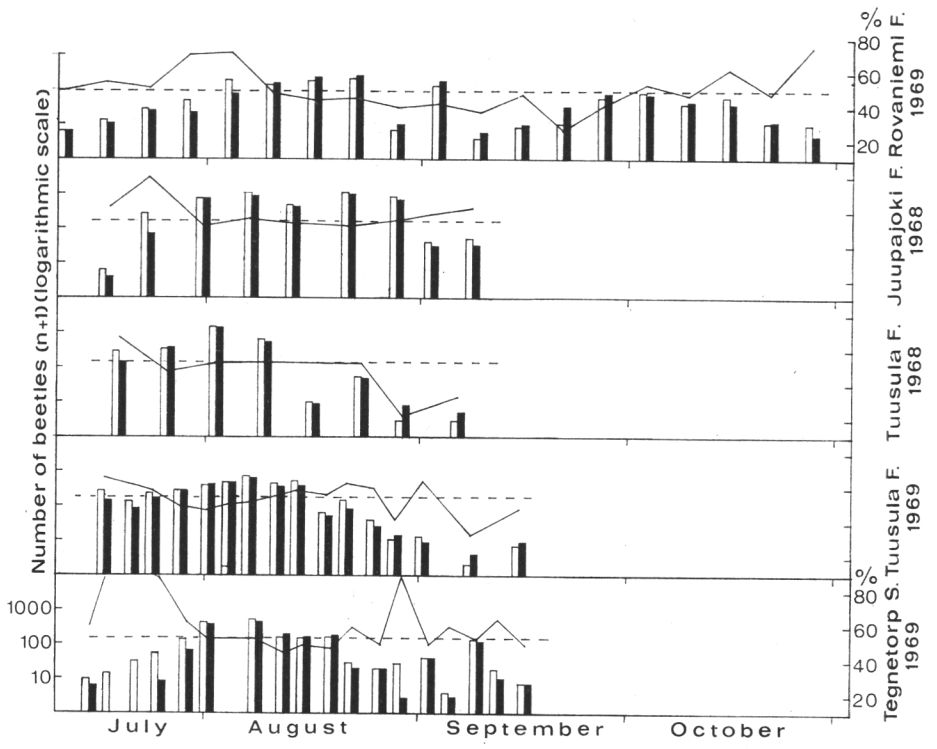

Fig. 7. The sex ratios in samples of *Trypodendron lineatum* emerging from the brood log. For explanations, see the legend to Fig. 6.

which 366 were males and 299 females. The difference is significant ($\chi^2 = 6.750$ $P < 0.01$).

Table 3 shows sex ratios from July 1 to September 30. The difference was statistically significant (more females than males) in one case (Tuusula 1968) and even then the difference was significant only at the 5 per cent level. But the proportion of females was higher during this period than during flight and emergence.

4. DISCUSSION

4.1. Flight and temperature

Like many other bark beetles, *Trypodendron lineatum* does not take flight until the air temperature has reached a certain degree of warmth. In Switzerland, according to H a d o r n (1933), flight activity begins at temperatures above 12°C in spring after the snow has melted. According to

Table 1. Sex ratios in samples of *Trypodendron lineatum* during the flight period (April—June).

Year, locality	Males		Females		Total	χ^2
	no.	%	no.	%		
1968						
Tegnetorp S	1 260	70.6	525	29.4	1 785	302.646***
Tuusula F	9 976	56.4	7 704	43.6	17 680	291.966***
Juupajoki F	3 995	58.9	2 794	41.1	6 789	212.462***
1969						
Tegnetorp S	740	51.9	686	48.1	1 426	2.044
Tuusula F	1 496	57.9	1 087	42.1	2 583	64.762***
Rovaniemi F	2 112	51.6	1 978	48.4	4 090	4.390*
Total	19 579		14 774		34 353	

Table 2. Sex ratios in samples of *Trypodendron lineatum* during emergence from the brood log.

Year, locality	Males		Females		Total	χ^2
	no.	%	no.	%		
1968						
Tegnetorp S						
Tuusula F	2 739	52.9	2 434	47.1	5 173	17.982***
Juupajoki F	4 504	54.5	3 766	45.5	8 270	65.856***
1969						
Tegnetorp S	1 955	53.7	1 687	46.3	3 642	19.722***
Tuusula F	3 769	54.5	3 145	45.5	6 914	56.318***
Rovaniemi F	1 264	49.6	1 284	50.4	2 548	0.156
Total	14 231		12 316		26 547	

Table 3. Sex ratios in samples of *Trypodendron lineatum* during the re-attack period (July—September).

Year, locality	Males		Females		Total	χ^2
	no.	%	no.	%		
1968						
Tegnetorp S						
Tuusula F	238	45.7	283	54.3	521	3.886*
Juupajoki F	191	51.2	182	48.8	373	0.218
1969						
Tegnetorp S	103	51.5	97	48.5	200	0.182
Tuusula F	53	46.5	61	53.5	114	0.562
Rovaniemi F	56	58.3	40	41.7	96	2.666
Total	641		663		1 304	

investigations made in Poland by Capecki (1967), the ambrosia beetle needs a temperature of 14°C to begin flight but before that average day temperatures must have been above 3°C for two weeks. According to Nuorteva (1956), Novak (1960) and Schwerdtfeger (1970), the threshold temperature is 16°C. Novak (1960) maintains that during flight, the temperature in forest soil should be 8—10°C. According to in-

vestigations made in North America, flight activity begins at 60°F (15.6°C) (Chapman & Kinghorn 1958, Chapman 1962, Rudinsky & Daterman 1964a, Dyer & Chapman 1965). Obviously, it is difficult to determine an accurate threshold temperature for flight activity, because temperatures may vary in different parts of the terrain by several degrees centigrade but in the light of the results obtained in the present investigation an air temperature of 15°C may be regarded as the threshold temperature for *Trypodendron* flight activity.

According to Rudinsky & Daterman (1964a), flights begin to drop as temperatures rise above 80°F (26.6°C) and virtually cease above 86°F (30°C). On days when noon temperatures exceed 30°C, flights occur only in the morning and afternoon. According to Hadorn (1933), diurnal flight begins at 11:00 reaches a maximum at 15:00 hours and ceases at 17:00. According to Rudinsky & Daterman (1964a), diurnal flight ceases about one hour before sunset even if temperatures are high enough.

In Central Europe, flight activity may begin as early as mid-March but mostly in April. In the Highlands of Germany, flights occur about one month later (Hadorn 1933, Schindler 1967, 1969, Capecki 1967) In Canada, *T. lineatum* is in flight in April and May (Chapman & Kinghorn 1958, Chapman & Neitsch 1959, Chapman & Dyer 1960, Dyer 1962, Chapman 1962, Rudinsky & Daterman 1964a, Dyer & Chapman 1965). However, in any one locality, there may be considerable differences between different parts of the terrain (Dyer 1962).

According to Hadorn (1933), the flight period lasts for 10 to 30 days, depending on weather conditions. According to investigations made in Canada, the flight period lasts for 1 to 1 ½ months with most of the beetles on the move in the beginning of this period (Chapman & Kinghorn 1958, Chapman 1962, Rudinsky & Daterman 1964a, Dyer & Chapman 1965). Flight occurs to some extent throughout the summer (Rudinsky & Daterman 1964a, Chapman & Kinghorn 1958).

As for the flight activity of *T. lineatum*, the results of the present investigation agree well with those of earlier investigations.

4.2. Emergence

Development from the egg stage to the emergence of the brood from the host tree takes 8 to 14 weeks (Hadorn 1933, Prebble & Graham 1957, Schwerdtfeger 1963, Capecki 1967). Hadorn (1933)

stated that *T. lineatum* has four larval stages, but Novak (1963 b) and Lekander (1968) have found only two.

According to the literature, the brood begins to emerge from the host tree in early July. Emergence is most abundant in late July but continues to some extent into September (Chapman & Neitsch 1959, Dyer & Kinghorn 1961, Dyer 1963, Schwerdtfeger 1963, Rudinsky & Daterman 1964 a, Dyer & Chapman 1965). According to Rudinsky & Daterman (1964 a), the parent beetles leave their tunnels at the same time as the callow adults leave their brood logs.

Attacks also occur to some extent in July and August. These observations have led to the assumption that *T. lineatum* is bivoltine (Escherich 1923, Gäbler 1955). Later, however, it has been found that the beetle has one generation a year and that attacks toward the end of the summer are made by parent beetles establishing a second brood (Hadorn 1933, Chapman 1955, Chapman & Kinghorn 1958, Schwerdtfeger 1963, Rudinsky & Daterman 1964a, Daterman et al. 1965, Capecki 1967, Schindler 1967). According to Dyer & Chapman (1965), only a small proportion of the parent beetles establishes a second brood. These workers observed that callow adults can also bore into the wood but do not do so for breeding purposes. Also, they have found that 90 to 98 per cent of the beetles in flight during re-attack are parent beetles. Novak (1963 a) stated that the flying activity of the young beetles is reduced because they enter into an imaginal diapause. According to Chapman & Kinghorn (1958), attacking beetles spend much more time in flight than beetles going to overwintering quarters, and thus are trapped in greater numbers. The results of the present investigation confirm the view that in the Nordic countries *T. lineatum* has only one generation a summer and that establishment of a second brood is relatively rare. Although a certain number of beetles were caught in the window traps in late summer, no signs (boring dust) of re-attack were found in the logs used as attractants in the traps. It may be that these logs were no longer attractive, for Dyer & Chapman (1965) state that trees loose their attractiveness as the frequency of attack increases. On the other hand in Tuusula in 1968 stumps on the experimental site were attacked in late August although no egg-laying occurred. The number of re-attacking beetles may depend on current temperatures. The samples of beetles collected with net funnels in connection with the study of the emergence of the brood undoubtedly included old parent beetles as well. According to Chapman & Nijholt (1965), 1 to 30 per cent of overwintered beetles taking flight in spring had already bred the previous year.

4.3. Sex ratio

In the literature, there is relatively little information on the sex ratios of *T. lineatum*. According to Chapman & Kinghorn (1958), in one year more females may be caught in window traps, but the following year the situation may be just the opposite. Capecki (1967) reports a sex ratio of 1 : 1. Dyer & Chapman (1965) noted that 60 to 79 per cent of the beetles caught in window traps during the re-attack period were females. In the present investigation, males were caught in larger numbers during both emergence and flight. On the other hand, balanced sex ratios were found during the re-attack period (July—September). In some bark beetle species females are known to be more numerous than males. In *Ips tridens* Mannerheim (Hopping 1962, 1964) and *Ips acuminatus* Gyll. (Bakke 1968 b), this is due to the existence of two kinds of females, some producing young of both sexes, others only females. According to Smith (1962), the eggs of the latter females do not become fertilized, the sperm only activating their development. MacLean & Giese (1967), in their breeding experiments with *Xyloterinus politus* (Say), obtained 84 per cent females. According to Annila (1971), in *Ips typographus* L. females outnumber males during both emergence and the flight period. According to Salonen et al. (1968), *Blastophagus piniperda* L. has a sex ratio of 1:1 after emergence, but during the spring flight, females are more numerous. Bakke (1968 a) has found that the two sexes of *B. piniperda* occur in almost equal numbers during flight until mid-May but later males are more numerous. The excess of *T. lineatum* males during emergence discovered in the present study cannot be explained on the basis of the results obtained. On the other hand, it is possible that males fly more actively than females during the flight period and thus are caught in window traps in greater numbers. In his studies on orientation in *T. lineatum*, Chapman (1966) found that males are caught in window traps in greater numbers than females in May and June if logs attacked only by females are used as attractants. During re-attack in July—August, the situation is just the opposite. In his view, this may be because the males fly more actively or respond more vigorously to »secondary» attractants produced by the females. On the other hand, if logs protected from attack were used as attractants, males represented 51 per cent of the total caught during flight. According to Chapman (1960), there are no significant differences in mortality between the sexes during hibernation.

4.4. Number of generations

It is interesting to note that *T. lineatum* has only one generation a year over its entire area of occurrence, which is so extensive that the duration

and warmth of the summer in its different parts are highly dissimilar. Some other bark beetles, for instance many *Ips* species, have two or even three generations during warm summers in Central Europe (S c h w e r d t f e g e r 1970) but in Finland only one (S a a l a s 1949). In the northern parts of the range of *T. lineatum* (e.g. northern Finland), the summer is just long enough to allow one new generation to develop. In Central Europe, on the other hand, the warm season is often long enough for two generations to develop each summer. This does not happen, but the callow beetles seek their way to their overwintering quarters in the middle of the summer. This behavioral mechanism is regulated by a powerful diapause lasting 8 to 9 months (cf. W i c h m a n n 1954, N o v a k 1963 a), which is released only during hibernation.

5. SUMMARY

1. The main purpose of the present investigation was to study the flight, attack, and emergence from brood logs of *Trypodendron lineatum* (Oliv.) in the Nordic countries. Some of the material was also used for sex ratio determinations.

2. The investigation was conducted at 10 localities in Denmark, Finland, Norway and Sweden in the years 1968—1969.

3. For the study of flight activity, spruce logs felled toward the end of the previous year were used as attractants, and beetles were collected in window traps. Attack was studied by counting the number of entry holes. Beetles emerging from brood logs were collected in emergence bag traps. The beetles were sexed by inspecting the head, which is convex in females and concave in males.

4. After the snow had melted, flight activity began when the temperature reached 15°C. In 1968 this took place in Denmark and southern Sweden in mid-April, in southern Norway and southern Finland in late April and in central Finland in late April or early May. In 1969, flight activity began in Denmark in late April, in southern Norway, southern Sweden and southern Finland in early May, in northern Sweden in late May and in northern Finland in early June. Flight activity mainly took place during the first two weeks but continued to some extent for 1 to 2 months. Beetles were on the move throughout the summer.

5. Attack took place immediately after flight.

6. On all experimental sites emergence from brood logs began in early July reaching a peak in late July or early August. In September, emergence was low except in Denmark and northern Finland, where it still occurred on a considerable scale in September and October.

7. Males outnumbered females almost without exception during both flight and emergence. On the other hand, there were no statistically significant differences in the sex ratios of beetles caught in window traps in mid- and late summer.

REFERENCES

Annila, E. 1971. Sex ratio in *Ips typographus* L. (Col., Scolytidae). — Ann. Ent. Fenn. 37: 7—14.

Austarå, Ø. & Saether, T. 1965. Angrep av den stripete vedboreren i ubarket grantømmer hogd til forskjellig årstid. (Summary: Infestation by *Trypodendron lineatum* Ol. of unbarked spruce logs felled at different seasons.) — Norsk Skogsbruk 11: 121—122.

Bakke, A. 1960. Insektskader på ubarket gran- og furutømmer i Norge. (Summary: Insect injuries to unbarked spruce and pine timber in Norway.) — Meddel. Norske Skogforsøksvesen 16: 281—333.

—»— 1968 a. Ecological studies on bark beetles (Coleoptera: Scolytidae) associated with Scots Pine (*Pinus silvestris* L.) in Norway, with particular reference to the influence of temperature. — Meddel. Norske Skogsforsøksvesen 83: 443—602.

—»— 1968 b. Field and laboratory studies on the sex ratio in *Ips acuminatus* (Coleoptera: Scolytidae) in Norway. — Can. Ent. 100: 640—648.

Bletchly, J. D. 1961. A review of factors affecting ambrosia beetle attack in trees and felled logs. — Emp. For. Rev. 40: 13—18.

Bletchly, J. D. & White, M. G. 1962. Significance and control of attack by the ambrosia beetle *Trypodendron lineatum* (Oliv.) (Col., Scolytidae) in Argyllshire Forests. — Forestry 35: 139—163.

Borden, J. H., Brownlee, R. G. & Silverstein, R. M. 1968. Sex pheromone of *Trypodendron lineatum* (Coleoptera: Scolytidae): production, bio-assay, and partial isolation. — Can. Ent. 100: 629—636.

Borden, J. H. & Slater, C. E. 1969. Sex pheromone of *Trypodendron lineatum*. Production in the female hindgut-Malpighian tubule region. — Ann. Ent. Soc. Amer. 62: 454—455.

Capecki, Z. 1967. Drwalnik paskowany — *Trypodendron lineatum* Ol. (Scolytidae, Coleoptera) na terenie polski. (Referat: Der gestreifte Nutzholzborkenkäfer — *Trypodendron lineatum* Ol. (Scolytidae, Coleoptera) in Polen.) — Prace Inst. Badawczego Leśnictwa 314: 3—80.

Castek, K. L., Barbour, J. F. & Rudinsky, J. A. 1967. Isolation and purification of the attractant of the striped ambrosia beetle. — J. Econ. Ent. 60: 658—660.

Chapman, J. A. 1955. Interpretation of adult history in the ambrosia beetle, *Trypodendron*. — Can. Dept. Agric. Forest Biol. Div. Bi-monthly Progr. Rep. 11 (6): 3—4.

—»— 1960. Overwintering mortality in the ambrosia beetle *Trypodendron*. — Can. Dept. Agric. Forest Biol. Div. Bi-monthly Progr. Rep. 16 (4): 3—4.

—»— 1961. A note on felling date in relation to log attack by the ambrosia beetle *Trypodendron*. — Can. Dept. Forestry, Forest Ent. Pathol. Branch, Bi-monthly Progr. Rep. 17 (5): 3—4.

Chapman, J. A. 1962. Field studies on attack flight and log selection by the ambrosia beetle *Trypodendron lineatum* (Oliv.) (Coleoptera: Scolytidae). — Can. Ent. 94: 74—92.

—»— 1966. The effect of attack by the ambrosia beetle *Trypodendron lineatum* (Oliver) on log attractiveness. — Can. Ent. 98: 50—59.

Chapman, J. A & Dyer, E. D. A. 1960. Seasonal flight activity of the ambrosia beetle, *Trypodendron lineatum* (Oliv.), for 1959, near Parksville, B. C. — Proc. Ent. Soc. Brit. Columbia 57: 30—33.

Chapman, J. A., Farris, S. H. & Kinghorn, J. M. 1963. Douglas-fir sapwood starch in relation to log attack by the ambrosia beetle, *Trypodendron*. — Forest Science 9: 430—439.

Chapman, J. A. & Kinghorn, J. M. 1955. Window flight traps for insects. — Can. Ent. 87: 46—47.

—»— 1958. Studies of flight and attack activity of the ambrosia beetle, *Trypodendron lineatum* (Oliv.), and other scolytids — Can. Ent. 90: 362—372.

Chapman, J. A. & Neitsch, R. 1959. Autumn-winter mortality in the ambrosia beetle. — Can. Dept. Agric. Forest Biol. Div. Bi-monthly Progr. Rep. 15 (3): 3—4.

Chapman, J. A. & Nijholt, W. W. 1965. Proportion of old and young adults in an overwintering population of the ambrosia beetle, *Trypodendron lineatum* (Oliv.). — Can. Dept. Forestry, Forest Ent. Pathol. Branch, Bi-monthly Progr. Rep. 21 (1): 3—4.

Christiansen, E. & Saether, T. 1968. Infestation density of *Trypodendron lineatum* (Oliver) (Coleoptera: Scolytidae) in relation to felling date of logs. — Norsk Ent. Tidsskr. 15: 28—30.

Daterman, G. E., Rudinsky, J. A. & Nagel, W. P. 1965. Flight patterns of bark and timber beetles associated with coniferous forests of western Oregon. — Agric. Exper. Stat. Oregon State Univ. Techn. Bull. 87.

Dyer, E. D. A. 1962. The effect of exposure of hibernation sites on the time of *Trypodendron* flight. — Can. Ent. 94: 910—915.

—»— 1963. Attack and brood production of ambrosia beetles in logging debris. — Can. Ent. 95: 624—631.

—»— 1967. Relation of attack by ambrosia beetle (*Trypodendron lineatum* Oliver) to felling date of spruce in central British Columbia. — Can. Dept. Forest Rural Div. Bi-monthly Res. Notes 23 (2): 11.

Dyer, E. D. A. & Chapman, J. A. 1965. Flight and attack of the ambrosia beetle *Trypodendron lineatum* (Oliver) in relation to felling date of logs. — Can. Ent. 97: 42—57.

Dyer, E. D. A. & Kinghorn, J. M. 1961. Factors influencing the distribution of overwintering ambrosia beetles, *Trypodendron lineatum* (Oliv.). — Can. Ent. 93: 746—759.

Escherich, K. 1923. Die Forstinsekten Mitteleuropas. II. — 663 pp. Berlin.

Fisher, R. C., Thompson, G. H. & Webb, W. E. 1953. Ambrosia beetles in forest and sawmill. Their biology, economic importance and control. Part I. Biology and economic importance. — Forestry Abstracts 14 (4): 381—389.

—»— 1954. Ambrosia beetles in forest and sawmill. Their biology, economic importance and control. Part II. Prevention and control. — Forestry Abstracts 15 (1): 3—15.

Francia, F. C. & Graham, K. 1967. Aspects of orientation behavior in the ambrosia beetle *Trypodendron lineatum* (Oliver). — Can. J. Zool. 45: 985—1002.

Graham, K. 1968. Anaerobic induction of primary chemical attractancy for ambrosia beetles (*Trypodendron lineatum*). — Can. J. Zool. 46: 905—908.

Gäbler, H. 1955. Forstschutz gegen Tiere. — 368 pp. Berlin.

Hadorn, C. 1933. Recherches sur la morphologie, les stages évolutifs et l'hivernage du bostryche liseré (*Xyloterus lineatus* Oliv.). — Beih. Zeitschr. Schweiz. Forstvereins 11: 1—120.

Hopping, G. R. 1962. The sex ratio in *Ips tridens* Mannerheim (Coleoptera: Scolytidae). — Can. Ent. 94: 506.

—»— 1964. The breeding evidence indicating two genetic types of females of *Ips tridens* (Mannerheim) (Coleoptera: Scolytidae). — Can. Ent. 96: 117—118.

Johnson, N. E. 1958. Ambrosia beetles infestation of coniferous logs on clear-cutting in northwestern Oregon. — J. Forestry 56: 508—511.

Lekander, B. 1968. The number of larval instars in some bark beetle species. — Ent. Tidskr. 89: 25—34.

Löyttyniemi, K. 1967. Tikaskuoriaisesta (*Trypodendron lineatum* Oliv., Col., Scolytidae) kuorellisen havupuutavaran pilaajana. (Referat: Über Beschädigungen des berindeten Nadelholzes durch *Trypodendron lineatum* Oliv. (Col., Scolytidae). — Silva Fennica 1(2): 49—57.

MacLean, D. B. & Giese, R. L. 1967. The life history of the ambrosia beetle *Xyloterinus politus* (Coleoptera: Scolytidae). — Can. Ent. 99: 285—299.

McMullen, D. L. 1956. Ambrosia beetles and their control in British Columbia. — Forestry Chron. 32: 31—43.

Moeck, H. A. 1970. Ethanol as the primary attractant for the ambrosia beetle *Trypodendron lineatum* (Coleoptera: Scolytidae). — Can. Ent. 102: 985—995.

Nijholt, W. W. 1970. The effect of mating and the presence of the male ambrosia beetle, *Trypodendron lineatum*, on »secondary» attraction. — Can. Ent. 102: 894—897.

Novak, V. 1960. Dřevokaz čárkovaný a boj proti němu. — Lesnické Aktuality 1. 132 pp. Praha.

—»— 1963 a. Investigation of diapause in the ambrosia beetle. — Comm. Inst. Forestalis Cechosloveniae 3: 23—43.

—»— 1963 b. Studie vývojových stupňů dřevokaza čárkovaného *Trypodendron lineatum* Ol. (Coleoptera, Scolytidae). (Summary: A study on the developmental stages of the striped timber beetle, *Trypodendron lineatum* Ol. (Coleoptera, Scolytidae). — Zool. Listy 12: 135—138.

Nuorteva, M. 1956. Über den Fichtenstamm-Bastkäfer, *Hylurgops palliatus* Gyll., und seine Insektenfeinde. — Acta Ent. Fenn. 13: 1—118.

Prebble, M. L. & Graham, K. 1957. Studies of attack by ambrosia beetles in softwood logs on Vancouver Island, British Columbia. — Forest Sci. 3: 90—112.

Pulliainen, E. 1965. Studies on the light and humidity reactions of *Trypodendron lineatum* (Oliv.) (Col., Scolytidae). — Ann. Ent. Fenn. 31: 197—208.

Reitter, E. 1916. Fauna Germanica. Die Käfer des Deutschen Reiches. V. — 168 pp. Stuttgart.

Rudinsky, J. A. 1966. Observations on olfactory behavior of Scolytid beetles (Coleoptera: Scolytidae) associated with Douglas-fir forests. — Zeitschr. Ang. Ent. 356—361.

Rudinsky, J. A. & Daterman, G. E. 1964 a. Field studies on flight patterns and olfactory responses of ambrosia beetles in Douglas-fir forest of western Oregon. — Can. Ent. 96: 1339—1352.

Rudinsky, J. A. & Daterman, G. E. 1964 b. Response of the ambrosia beetle *Trypodendron lineatum* (Oliver) to female-produced pheromone. — Zeitschr. Ang. Ent. 54: 300—303.

Rudinsky, J. A. & Schneider, I. 1968. On the olfactory behavior of *Trypodendron lineatum* (Oliv.). — Proc. XIII Congr. Ent., Moscow.

Rummukainen, U. 1964. Hyönteisten aiheuttamasta tuoreen kuorellisen havupuutavaran pilaantumisesta ja sen kemiallisesta estämisestä. (Summary: On deterioration of green softwood caused by insects and its chemical control.) — Comm. Inst. For. Fenn. 28 (5): 1—67.

Saalas, U. 1917, 1923. Die Fichtenkäfer Finnlands. I—II. — Ann. Acad. Scient. Fenn. A. VIII, 1—547, XXII, 1—746.

—»— 1919. Kaarnakuoriaisista ja niiden aiheuttamista vahingoista Suomen metsissä. (Referat: Über die Borkenkäfer und den durch sie verursachten Schaden in den Wäldern Finnlands.) — Acta Forestalia Fennica 10: 1—415.

—»— 1949. Suomen metsähyönteiset. — 719 pp. Helsinki.

Salonen, K., Pulliainen, E. & Koponen, M. 1968. Sex ratio in *Blastophagus piniperda* L. (Col., Scolytidae) in Finland. — Ann. Ent. Fenn. 34: 31—37.

Schindler, U. 1967. Borkenkäferbekämpfung unter besonderer Berücksichtigung der Rindenbrüter an Fichte und Kiefer sowie des gestreiften Nutzholzborkenkäfers. — Forst-technische Informationen 3: 15—23.

—»— 1969. Erfahrungen bei der letztjährigen Bekämpfung des gestreiften Nutzholzborkenkäfers. — Allgem. Forstzeitschr. 24: 205—206.

Schneider, I. & Rudinsky, J. A. 1969. The site of pheromone production in *Trypodendron lineatum* (Coleoptera: Scolytidae): bio-assay and histological studies of the hindgut. — Can. Ent. 101: 1181—1186.

Schwerdtfeger, F. 1963. Zur Generationsfrage beim gestreiften Nutzholzborkenkäfer *Xyloterus lineatus* Ol. — Forst- u. Holzwirt 18: 449—451.

—»— 1970. Waldkrankheiten. — 509 pp. Hamburg — Berlin.

Smith, G. S. 1962. Cytogenetic pathways in beetle speciation. — Can. Ent. 94: 941—955.

Subansenee, W. 1971. Flight period and emergence in Denmark of the adult bark beetle *Hylurgops palliatus* Gyll. (Coleoptera, Scolytidae). — R. Veter. Agric. Univ. Yearb. 1971, 114—123.

Wichmann, H. E. 1954. Scolytoidea, Borkenkäfer, Bark beetles. — Handb. Pflanzenkrankheiten V (2): 500—557.

Wood, S. L. 1957. Ambrosia beetles of the tribe Xyloterini (Coleoptera, Scolytidae) in North America. — Can. Ent. 89: 337—354.

SUOMEN METSÄVARAT JA METSIEN OMISTUS 1964—70 SEKÄ NIIDEN KEHITTYMINEN 1920—70

FOREST RESOURCES AND OWNERSHIP IN FINLAND 1964—70 AND THEIR DEVELOPMENT 1920—70

KULLERVO KUUSELA

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ALKUSANAT

Valtakunnan metsien V inventointi, joka alkoi koetyöllä v. 1963 ja varsinaisesti v. 1964 sekä saatiin kenttätyön osalta päätökseen v. 1970, on jouduttu toteuttamaan työmenetelmien ja tietojen kysynnän osalta voimakkaasti muuttuvissa oloissa. Teollisen puun käytön suureneminen on aikaansaanut tilanteita, joissa metsävaratietojen käyttäjät ovat odottaneet nopeata monipuolisten tulosten käsittelyä. Metsävarojen tutkimukseen keskittymisen kannalta olosuhteet eivät ehkä ole olleet kaikkein kiitollisimmat. Toisaalta ne ovat ylläpitäneet kannustavaa tietoisuutta, että inventoinnin tuloksilla on merkitystä ja käyttöä kehitettäessä metsätaloutta.

Inventoinnin suunnitteluun, johtamiseen, suoritukseen ja tulosten laskentaan on metsänarvioimisen tutkimusosaston henkilökuntaa osallistunut seuraavasti:

Erikoistutkija, tri Paavo Tiihonen: Kenttäryhmien koulutus, kenttätyön johto ja valvonta sekä maan pohjoispuoliskon mäntytukkipuustoa koskevan erillisselvityksen valmistaminen.

Vanhempi assistentti Sakari Salminen: Aineistojen tietojenkäsittelyn suunnittelu ja toteutus sekä kenttäryhmien koulutus ja valvonta aineiston käsittelyn toteutusta silmällä pitäen.

Nuorempi assistentti Alli Salovaara: Kenttäaineiston alkukäsittelyn ja tulosten laskennan eräät vaiheet ja julkaisutaulukoiden valmistaminen.

Tri Pentti Koivisto: Koivuvarojen erillistutkimukset.

Tri Veikko O. Mäkinen osallistui V inventointia varten suoritettuihin koeinventointeihin ja inventoinnin kenttätyön alkuvaiheisiin.

Tri Simo Poso: Enontekiön, Inarin ja Utsjoen kunnan koetyönä suoritetun inventoinnin suunnittelu ja toteutus.

Ryhmänjohtajina inventoinnissa ovat toimineet: Karl-Johan Ahlsved, Kari Borgman, Juhani Huittinen, Christian Keil, Markku Kiikka, Ilkka Kohmo, Aarno Koukkula, Matti Kujala, Jouko Laasasenaho, Veikko Laukkanen, Erkki Länsisyrjä, Heikki Mäki, Timo Nyrhinen, Simo Poso, Raimo Pökälä, Jorma Rajala, Jaakko Salo, Tarmo Uusitalo, Arno Uusvaara ja Lauri Vuorisalo. Varsinaisten ryhmänjohtajatehtävien lisäksi Matti Kujala on toiminut erityistehtävissä ryhmänjohtajana sekä osallistunut aineistojen tietokonekäsittelyyn. Erityistehtävissä ryhmänjohtajana on toiminut vielä Eero Siltovuori.

Kiitän edellä lueteltuja henkilöitä sekä muuta tutkimusosaston henkilökuntaa heidän panoksestaan, joka on tehnyt mahdolliseksi V inventoinnin toteutuksen.

Kenttätyötä ja ennen muuta metsänomistuksen selvitystä ovat tehokkaasti avustaneet metsähallitus, keskusmetsälautakunnat, piirimetsälautakunnat, Ahvenanmaan maakuntahallinnon metsäosasto, metsänhoitoyhdistykset ja teollisuusyhtiöiden metsäosastot, joille kaikille esitän parhaan kiitoksen.

Kullervo Kuusela

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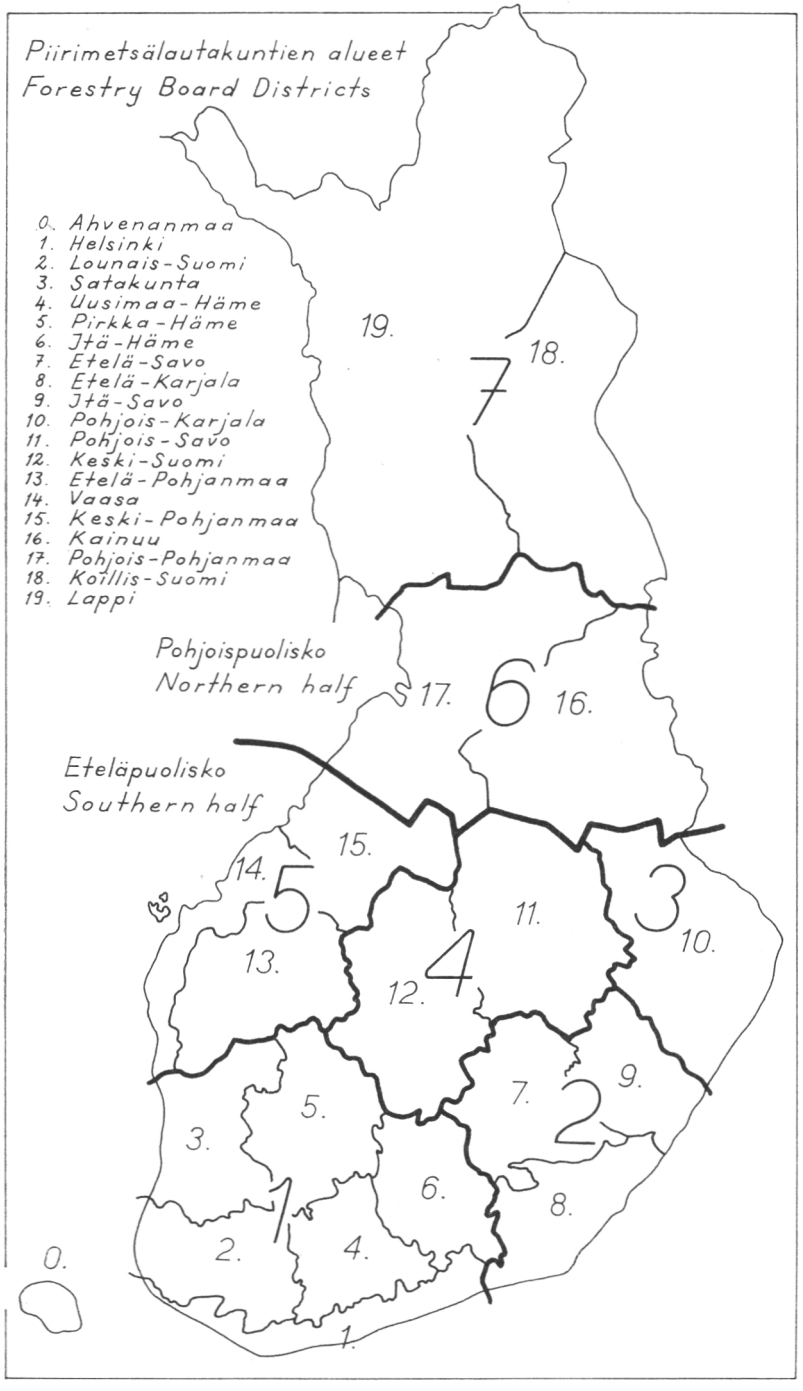


Kuva 1. Metsänomistusta koskevien tulosten laskenta-alueet.
Fig. 1. Calculation areas for the results of forest ownership.

JOHDANTO

Suomen metsävaroja on arvioitu vuodesta 1921 lähtien metsäntutkimuslaitoksen suorittamilla valtakunnan metsien inventoinneilla, joista kolme ensimmäistä toteutettiin noin 15 vuoden välein ja jotka 1960-luvun alusta lähtien ovat olleet jokavuotista näytteen mittaamista (Ilvessalo 1927, 1942, 1943, 1948, 1956, 1962, 1963; Tiihonen 1966, 1968; Kuusela and Salminen 1969; Kuusela 1970). IV inventoinnin tulokset kuvaavat metsävaroja vuosina 1960—63 ja V inventoinnin tulokset vuosina 1964—70. Kenttätyön etenemisestä johtuen V inventoinnin tulokset ovat vanhimmat maan lounaisosassa ja tuoreimmat Lapissa siten, että kuvan 1 kartalle merkitty alue 1 arvioitiin vuosina 1964—65, alueet 2 ja 3 v. 1966, alue 4 v. 1967, alue 5 v. 1968, alue 6 v. 1969 ja alue 7 v. 1970 (Kuusela 1966, 1967; Kuusela ja Salovaara 1968, 1969, 1971).

Lukuunottamatta IV inventointia arvioinnin kohteena ovat olleet myös metsien omistussuhteet, joita inventoinnin lisäksi on tutkittu suorittamalla pinta-alojen omistussuhteita koskevia tiedusteluja (Ilvessalo, M. 1959; Uusvaara 1969). Jälkimmäiset on toteutettu siten, että tiedustelemalla ja maataloustilastoa hyväksi käyttäen on selvitetty kaikkien muiden paitsi yksityismetsien ala, jonka jälkeen yksityismetsien ala on saatu vähentämällä muiden omistus kokonaispinta-alasta. Tiedustelun heikkoutena on, että metsätalouden maan ja sen alaluokkien käsitteet eivät ole samanlaiset kaikilla omistajilla. Tästä syystä tulokset poikkeavat inventointien tuloksista. Vaikka inventoinnin tuloksissa onkin satunnaisvirhettä, joka voi olla suhteellisesti sitä suurempi mitä pienemmästä pinta-alasta on kysymys, niin inventointien tulokset antanevat luotettavamman kuvan kehityksestä kuin tiedustelujen tulokset (Kuusela and Ervasti 1969).

Julkaisun toisen pääosan muodostavat V inventoinnin tulokset, jotka esitetään kuvassa 1 esitetyn aluejaon mukaisesti. Alueet 1—5 käsittävät maan eteläpuoliskon ja alueet 6 ja 7 pohjoispuoliskon. Osa-alueiden pienentäminen olisi lisännyt suuresti pinta-alaosuuksien satunnaisvirhettä niiden omistajien osalta, joilla on vähiten metsiä. Käytetyillä osa-alueillakin pienimmät osuudet ovat satunnaisvirheen vuoksi vain suuruusluokka-arvioita. Toisessa osassa kuvataan metsävarojen sekä metsänomistuksen kehittymistä vuosina 1920—70. Lähteinä on käytetty lueteltuja julkaisuja.

Tulosten kuvaus on yhtenä kokonaisuutena ennen liitetaulukoita. Liitetaulukot sisältävät pääosan numeroaineistosta. Muut sanalliseen kuvaukseen liittyvät taulukot sisältävät tärkeimpiä yhteenvetoja ja tietoja kehityksestä.

V inventoinnin näytteellä saatujen arvioiden luotettavuuslaskelmat ovat vielä työn alla ja niiden tuloksista valmistuu oma julkaisunsa. Aikaisempien selvitysten perusteella (Ilvessalo 1956) voidaan sanoa, että vähintään 10 miljoonan hehtaarin suuruisella alueella puuston kuutiomäärän keskivirhe on noin $\pm$ 0.7 % ja keskimääräisen piirimetsälautakunnan alueella enintään $\pm$ 3 %. Vastaavat kasvun arvion enimmäiskeskivirheet ovat $\pm$ 1 ja $\pm$ 4 %.

LUOKKIEN KUVAUKSET

Metsävaratietojen sisältö on kuvattu yksityiskohtaisesti »Valtakunnan metsien inventoinnin kenttäohjeessa». Seuraavassa kuvataan tärkeimpien luokitusten sisältö.

Maaluokat

M e t s ä m a a on sellaista puun kasvattamiseen käytettyä tai käytettävissä olevaa maata, jolla puuston keskimääräinen kasvu on suotuisimpien olosuhteiden vallitessa ja 100 vuoden kiertoaikaa käytettäessä vähintään 1 m³/ha kuorellista puuta (noin 0.85 m³/ha kuoretonta puuta).

K i t u m a a on edellä esitetyn mukaisesti sellaista maata (kiviperäistä tai kalliomaata, turvemaata, hietikkoa, laki- tai tunturimaata), jolla puuston kasvu on 0.9—0.1 m³/ha.

J o u t o m a a on edellä esitetyn mukaisesti sellaista maata, jolla puuston kasvu on alle 0.1 m³/ha.

Kitu- ja joutomaahan kuuluvista turvemaista voidaan osa muuttaa ojittamalla ja lannoittamalla metsämaaksi.

M e t s ä t a l o u d e n t i e t, v a r a s t o t jne. ovat sellaista metsätalouden piiriin kuuluvaa maata, joka pysyvästi tai tilapäisesti ei ole käytettävissä puun kasvattamiseen.

M e t s ä t a l o u d e n m a a on edellä kuvatun neljän maaluokan summa. Joutomaan ja metsätalouden teiden, varastojen jne. metsätalouden maahan kuulumisen edellytyksenä on, että ne sisältyvät metsä- ja kitumaan muodostamaan kokonaisuuteen.

M a a t a l o u d e n m a a käsittää pellot, laitumet ja niihin alueellisesti kuuluvat joutomaat, tilustiet ja maatalouden rakennuksiin liittyvät alueet.

R a k e n n u s t e n a l a käsittää asuntojen, talous- ja asutuskeskusten, tehtaiden jne. välittömine ympäristöineen vaatiman maan.

L i i k e n n e v ä y l ä t jne. käsittävät tiet, rautatiet, lentokentät, voimajohtolinjat ja vastaavat penkereineen ja ojineen.

Metsätalouden maan (metsä-, kitu- ja joutomaan) alaryhmät

K a n g a s on mineraalimaata.

S u o tai t u r v e m a a. Pintakasvillisuudesta on yli 75 % suokasvillisuutta. Turvemaa, jolla ei ole tätä määrää suokasvillisuutta, on ojittamalla suosta kuivatettu.

K o r p i on yleensä kuusi- tai lehtipuuvaltainen turvemaa.

R ä m e on yleensä mäntyvaltainen turvemaa.

N e v a on luontaisesti puuton turvemaa.

Korpi tai räme voivat olla hakkuun jälkeen puuttomia.

Omistajat

Yksityinen. Käsite sisältää myös yksityisten toiminimien ja perikuntien omistamat tilat sekä hallintasopimustilat.

Osakeyhtiö, ei kuitenkaan asunto-osakeyhtiö.

Valtio, käsittää metsähallituksen, metsäntutkimuslaitoksen, puolustusministeriön ja muut metsää omistavat valtion virastot tai laitokset.

Kunta ja seurakunta.

Yhteisö käsittää säätiöt, osuuskunnat, kommandiitti- ja asunto-osakeyhtiöt ja muut yhteisöt.

Kasvupaikkatyypit

1. Lehto käsittää kankaiden lehtotyypit ja lehtomaiset sekä lettosuot ja turvemaat.
2. Lehtomaiset kankaat ja vastaavat turvemaat. Kankaiden metsätyypit Etelä-Suomessa ovat käenkaali-mustikka- (OMT) ja talvikkityyppi (PyT); Pohjanmaalla-Kainuussa kurjenpolvi-käenkaali-mustikkatyyppi (GOMT); Perä-Pohjolassa kurjenpolvi-mustikkatyyppi (GMT). Suot ja turvemaat käsittävät ruohoisia suotyyppejä.
3. Tuoreet kankaat ja vastaavat turvemaat. Kankaiden metsätyyppi Etelä-Suomessa on mustikkatyyppi (MT); Pohjanmaalla-Kainuussa puolukka-mustikkatyyppi (VMT), joka kauan kuusta kasvaneena esiintyy veroluokkaa alentavasti kunttaisena, ja metsälauha-mustikkatyyppi (DeMT); Perä-Pohjolassa seinäsammal-mustikkatyyppi (HMT), joka esiintyy usein veroluokkaa alentavasti vahvasti kunttaisena. Suot ja turvemaat ovat suursaraisia ja mustikkaisia suotyyppejä.
4. Kuivahkot kankaat ja vastaavat turvemaat. Kankaiden metsätyyppi Etelä-Suomessa on puolukkatyyppi (VT); Pohjanmaalla-Kainuussa variksenmarja-puolukkatyyppi (EVT); Perä-Pohjolassa variksenmarja-mustikkatyyppi (EMT). Suot ja turvemaat ovat piensaraisia ja puolukkaisia suotyyppejä.
5. Kuivat kankaat ja vastaavat turvemaat. Kankaiden metsätyyppi Etelä-Suomessa on kanervatyyppi (CT); Pohjanmaalla-Kainuussa variksenmarja-kanervatyyppi (ECT) ja Perä-Pohjolassa mustikka-kanerva-jäkälätyyppi (MCClT). Suot ja turvemaat ovat tupasvillaisia ja isovarpuisia suotyyppejä.
6. Karukko kankaat ja vastaavat turvemaat. Kankaiden metsätyyppi on jäkälätyyppi (ClT). Suot ja turvemaat ovat rahkaisia suotyyppejä.

Metsätalouden maan veroluokat

IA: lehdot ja lehtomaiset kankaat sekä turvekankaat.
IB: tuoreet ja talvikkityypin kankaat sekä turvekankaat.
II: kuivahkot ja kunttaantuneet puolukka-mustikkatyypin kankaat sekä turvekankaat.
III: kuivat, karukko- ja kunttaantuneet seinäsammal-mustikkatyypin kankaat ja metsämaan korvet.
IV: metsämaan rämeet.
V: kitumaan rämeet.
J: metsätalouden joutomaa.

Puuston kasvua alentavien tekijöiden perusteella maa voidaan määrittää kasvupaikkatyyppiään alempaan veroluokkaan.

Turvemaiden kuivumisaste

L u o n n o n t i l a i n e n suo.

O j i k k o on ojitettu suo, jossa ojien vaikutus ei ole vielä havaittavissa pintakasvillisuudessa eikä sanottavasti puustossakaan. Se voi olla metsä-, kitu- tai joutomaata.

M u u t t u m a on ojitettu suo, jossa ojitus on lisännyt puiden kasvua, mutta jossa alkuperäinen suotyyppi antaa pintakasvillisuudelle vielä leimansa. Se on metsämaata.

T u r v e k a n g a s on ojitettu suo, jolla puusto on sulkeutunut ja jonka pintakasvillisuus muistuttaa jotain kankaiden metsätyyppiä. Se on metsämaata.

Puutavaralajit

Sahatukkirungon läpimitta rinnankorkeudella on vähintään 19.5 cm ja tukin pienin latvaläpimitta noin 6 tuumaa. Paperipuu on puolipuhdasta 2 metristä ja pölkyn pienin läpimitta 8 cm kuoren päältä. Ohutpuu on kuorellista, 1 metristä ja pienin läpimitta 5 cm.

MAA

Maaluokat

Suomen maapinta-alan jakaantuminen maaluokkiin V inventoinnin tulosten mukaan on esitetty taulukossa 1 ja kankaiden sekä turvemaiden jakaantuminen taulukoissa 2 ja 3. Kuten taulukon 4 tietojen perusteella voidaan todeta, kolmessa ensimmäisessä inventoinnissa käytössä ollut kasvullinen metsämaa käsittää maan eteläpuoliskossa selvästi pienemmän ja

Taulukko 1. Maaluokat vuosina 1964—70 V inventoinnin tulosten mukaan.
Tabel 1. Land classes in 1964—70 on the basis of the results of 5th forest inventory.

Maaluokka *Land class*	Eteläpuolisko *Southern half*		Pohjoispuolisko *Northern half*		Yhteensä *Total*	
	%	1 000 ha	%	1 000 ha	%	1 000 ha
Metsämaa — *Forest land*	68.0	10 944	53.6	7 753	61.2	18 697
Kitumaa — *Poorly productive land*	5.9	944	18.9	2 730	12.0	3 674
Joutomaa — *Waste land*	5.2	836	23.4	3 390	13.9	4 226
Tiet, varastot, jne. — *Roads, depots, etc.*	0.3	43	0.2	27	0.2	70
Yhteensä metsätalouden maa — *Total forestry land*	79.4	12 767	96.1	13 900	87.3	26 667
Maatalouden maa — *Agricultural land*	18.1	2 920	2.9	411	10.9	3 331
Rakennusten ala — *Built-up areas*	1.4	225	0.3	41	0.9	266
Liikenneväylät, jne. — *Communication routes, etc.*	1.1	177	0.7	107	0.9	284
Yhteensä muu maa — *Total other land*	20.6	3 322	3.9	559	12.7	3 881
Yhteensä koko maa — *Total land*	100.0	16 089	100.0	14 459	100.0	30 548

Taulukko 2. Kankaiden jakaantuminen maaluokkiin 1964—70.
Table 2. Mineral soils by land classes in 1964—70.

Alue *Area*	Metsämaa *Forest land*		Kitumaa *Poorly prod. land*		Joutomaa *Waste land*		Yhteensä *Total*	
	1 000 ha	%	1 000 ha	%	1 000 ha	%	1 000 ha	%
Eteläpuolisko — *Southern half*	8 460	96.6	210	2.4	89	1.0	8 759	100.0
Pohjoispuolisko — *Northern half*	6 289	77.6	861	10.6	960	11.8	8 110	100.0
Koko maa — *Whole country*	14 749	87.4	1 071	6.4	1 049	6.2	16 869	100.0

Taulukko 3. Turvemaiden jakaantuminen maaluokkiin ja alaryhmiin 1964—70.
Table 3. Peatlands by classes and sub-groups in 1964—70.

Alue *Area*	Maaluokka *Land class*	Korpi *Spruce and deciduous swamp*		Räme *Pine swamp*		Neva *Open swamp*		Yhteensä *Total*		
		1 000 ha	%	1 000 ha	%	1 000 ha	%	1 000 ha	%	
Eteläpuolisko *Southern half*	Metsämaa — *Forest land*	1 171	47.1	1 313	52.9	—	—	2 484	100.0	62.7
	Kitumaa — *Poorly productive land*	68	9.3	666	90.7	—	—	734	100.0	18.5
	Joutomaa — *Waste land*	16	2.1	325	43.5	406	54.4	747	100.0	18.8
	Yhteensä — *Total*	1 255	31.7	2 304	58.1	406	10.2	3 965	100.0	100.0
Pohjoispuolisko *Northern half*	Metsämaa — *Forest land*	548	37.4	916	62.6	—	—	1 464	100.0	25.4
	Kitumaa — *Poorly productive land*	370	19.8	1 499	80.2	—	—	1 869	100.0	32.4
	Joutomaa — *Waste land*	107	4.4	671	27.6	1 652	68.0	2 430	100.0	42.2
	Yhteensä — *Total*	1 025	17.8	3 086	53.5	1 652	28.7	5 763	100.0	100.0
Koko maa *Whole country*	Metsämaa — *Forest land*	1 719	43.5	2 229	56.5	—	—	3 948	100.0	40.6
	Kitumaa — *Poorly productive land*	438	16.8	2 165	83.2	—	—	2 603	100.0	26.7
	Joutomaa — *Waste land*	123	3.9	996	31.3	2 058	64.8	3 177	100.0	32.7
	Yhteensä — *Total*	2 280	23.4	5 390	55.4	2 058	21.2	9 728	100.0	100.0

Taulukko 4. Metsämaan, aikaisemmin kasvullisen metsämaan, ja metsätalouden maan osuus inventointien tulosten mukaan.

Table 4. Proportions of forest land, earlier productive forest land, and of forestry land in results of the inventories.

Maaluokka *Land class*	1921—24[1])	1936—38	1951—53[2])	1960—63[2])	1964—70[3])
	% maa-alasta tai 1 000 ha *% of land area or 1 000 ha*				
	Eteläpuolisko — *Southern half*				
Metsämaa — *Forest land*	64.6	64.7	61.9	67.3	68.0
Metsätalouden maa — *Forestry land*	80.0	79.5	77.6	76.4	79.4
Koko maa-ala — *Total land area*	17 458	18 586	16 090	16 090	16 089
	Pohjoispuolisko — *Northern half*				
Metsämaa — *Forest land*	52.4	46.5	51.2	59.7	53.6
Metsätalouden maa — *Forestry land*	96.6	96.9	95.8	96.5	96.1
Koko maa-ala — *Total land area*	16 902	16 265	14 450	14 450	14 459
	Koko maa — *Whole country*				
Metsämaa — *Forest land*	58.6	56.2	56.8	63.7	61.2
Metsätalouden maa — *Forestry land*	88.2	87.6	86.1	85.9	87.3
Koko maa-ala — *Total land area*	34 360	34 850	30 540	30 540	30 548

[1]) Lääninjaon mukainen etelä- ja pohjoispuolisko. — *Southern and Northern half based on the boundaries of administrative districts.*

[2]) Pinta-alasuhteisiin ovat vaikuttaneet sodanjälkeiset alueluovutukset. — *Land class proportions have been changed because of the ceded areas after the war.*

[3]) Metsämaata on aiemmin vastannut kasvullinen metsämaa. — *Forest land has been in earlier inventories productive forest land.*

pohjoispuoliskossa lähes yhtä suuren pinta-alan kuin nykyisin käytössä oleva metsämaa (vert. määritelmä s. 9). Ennenmuuta maan eteläpuoliskossa metsämaahan sisältyy kasvullisen metsämaan lisäksi paras osa aikaisempaa huonokasvuista metsämaata. Kaikkein pohjoisimmilla alueilla metsämaan osuus saattaa olla hieman pienempi kuin aikaisemman kasvullisen metsämaan osuus. Lapin piirimetsälautakunnan alueella III ja V inventoinnin tulosten mukaan ne ovat likimain yhtä suuret.

Kankaiden ja turvemaiden, so. ojittamattomien ja ojitettujen soiden raja on tullut arvioiduksi eri inventoinneissa varsin täsmällisesti samaperusteisesti, sillä turvemaiden ala saatiin III inventoinnissa 9 742 000 ha:ksi ja V inventoinnissa 9 728 000 ha-ksi.

Taulukon 4 perusteella voi tehdä päätelmiä metsätalouden maan ja metsämaan osuuden kehittymisestä vuosina 1920—70. Aikajakson alussa aina 1950 luvulle asti metsätalouden maa ja metsämaa pienenivät pääasiassa peltojen mutta myös teiden ja rakennetun alan lisääntymisen vuoksi. Tämän jälkeen metsätalouden maa on alkanut lisääntyä maatalouden maan metsittymisen takia. Näin tapahtuva metsätalouden maan lisääntyminen kiihtynee lähitulevaisuudessa ja johtanee kuluvalla vuosisadalla metsämaan

suurenemiseen ainakin noin 0.6 milj. ha:lla. Lisäksi soiden ojitus lisää metsämaata muuttamalla kitu- ja joutomaan soita parempaan kasvuluokkaan. Tämä muutos on voimakkaimmillaan 1970- ja 80-luvulla ja lisää kuluvalla vuosisadalla ojitusohjelmien mukaan metsämaata vajaat 4 milj. ha.

Maan ja metsämaan omistus

Maan omistusta koskevat tiedot perustuvat tilastoihin ja tiedusteluihin. Niitten tulosten mukainen maan omistus v. 1965 ja sitä edeltänyt kehitys on esitetty taulukossa 5. Yksityinen maan omistus on lisääntynyt koko itsenäisyyden ajan uusien tilojen muodostamisen ja asutuksen kautta. Voimakkaimmillaan se oli 1940- ja 50-luvulla ja lienee kutakuinkin pysähtynyt 1960-luvun lopulla. Suurin maan luovuttaja on ollut valtio, mutta myös osakeyhtiöt, kunnat ja seurakunnat ovat olleet maan luovuttajia. Uutena omistusmuotona on tilastoon ilmaantunut yhteisö. Se käsittää pääosaksi yhteismetsiä ja myös säätiöitä. Kuntien ja seurakuntien maaomaisuus on muuttunut suurenevaksi sen jälkeen, kun uusien yksityistilojen muodostamisen huippu oli sivuutettu.

Kun Suomen nykyistä maa-alaa pidetään vertauskohtana, on maaomaisuuden siirto yksityisomistukseen itsenäisyyden aikana ollut 3 055 000 ha, minkä lisäksi yksityisten omistamia yhteismetsiä on perustettu noin 300 000 ha. Saman vertausperusteen mukaan valtion maaomaisuus on pienentynyt 3 360 000 ha ja yhtiöiden 275 000 ha.

Metsämaan ja metsätalouden maan omistus V inventoinnin tulosten mukaan on esitetty taulukossa 6 ja metsämaan omistuksen kehitys inventointien tulosten mukaan taulukossa 7. Kun otetaan huomioon, että valtion

Taulukko 5. Maan omistus 1920- ja 1960-luvuilla tilastojen ja pinta-alatiedustelujen mukaan.

Table 5. Land ownership in 1920s to 1960s based on statistics and inquiries.

Ajankohta *Time*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*	Maa-ala *Land area*
	% maa-alasta — % *of land area*						1 000 ha
1922	52.1	6.4	39.7	1.8	—	100.0	34 360
1938	54.1	6.4	37.3	2.2	—	100.0	34 360
1944	56.2	6.4	35.1	2.3	—	100.0	34 848
1953	60.9	5.6	31.8	1.7	—	100.0	34 848
1957	61.9	5.6	30.7	1.8	—	100.0	30 540
1965	62.1	5.5	28.7	2.0	1.7	100.0	30 547

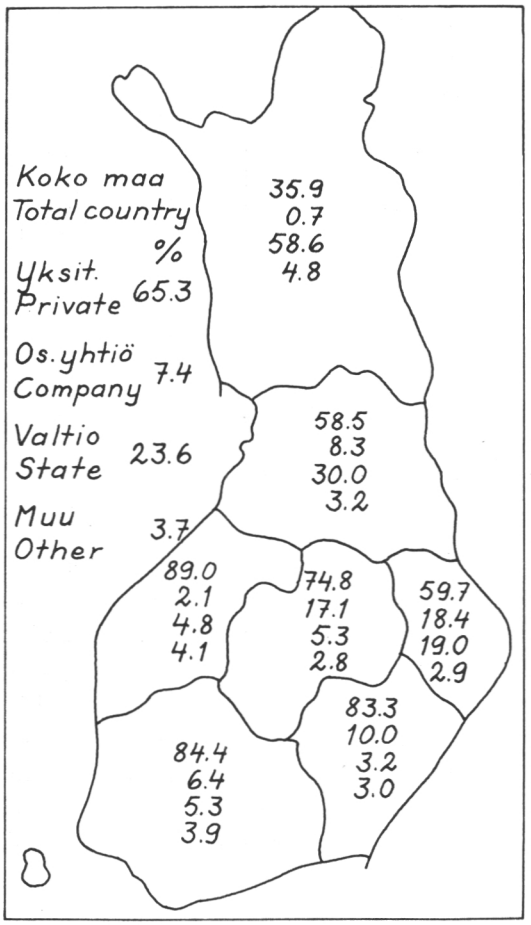
Taulukko 6. Metsämaan ja metsätalouden maan omistus 1964—70.
Table 6. Ownership of forest and forestry land in 1964—70.

Maaluokka *Land class*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune church*	Yhteisö *Corporation*	Yhteensä *Total*	
	%						1 000 ha
	Eteläpuolisko — *Southern half*						
Metsämaa — *Forest land*	80.0	10.1	6.5	2.4	1.0	100.0	10 944
Metsätalouden maa — *Forestry land*	78.9	10.1	7.4	2.4	1.2	100.0	12 767
	Pohjoispuolisko — *Northern half*						
Metsämaa — *Forest land*	44.4	3.6	47.8	1.2	3.0	100.0	7 753
Metsätalouden maa — *Forestry land*	38.7	2.8	55.1	0.9	2.5	100.0	13 900
	Koko maa — *Whole country*						
Metsämaa — *Forest land*	65.3	7.4	23.6	1.9	1.8	100.0	18 697
Metsätalouden maa — *Forestry land*	58.0	6.3	32.2	1.6	1.9	100.0	26 667

maa-alasta on suhteellisesti paljon enemmän kitu- ja joutomaata kuin muilla omistajilla ja että uusia yksityistiloja perustettaessa on valtion maista otettu suhteellisesti enemmän metsämaata kuin mikä on ollut metsämaan osuus valtion maa-alasta, niin inventointien tulokset vastaavat hyvin muita tietoja. Metsämaan omistusta koskevista muutoksista voidaan tässä todeta, että nykyistä metsämaan kokonaisalaa lähtökohtana pitäen yksityisomistuksessa oleva metsämaa on lisääntynyt noin 2 milj. ha 1920-luvun alusta lähtien.

Taulukko 7. Metsämaan omistus 1920- ja 1960-luvuilla valtakunnan metsien inventointien mukaan.
Table 7. Forest land ownership in 1920s to 1960s based on the results of the national forest inventories.

Ajankohta *Time*	Maaluokka *Land class*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yht. *Total*	Maa-ala *Land area*
		% maa-alasta — % *of land area*						1 000 ha
1921—24	Kasv. metsämaa — *Productive forest land*	54.9	8.0	35.3	1.8	—	100.0	20 138
1936—38	Kasv. metsämaa — *Productive forest land*	55.3	8.4	33.7	2.6	—	100.0	19 580
1951—53	Kasv. metsämaa — *Productive forest land*	62.3	7.4	28.3	2.0	—	100.0	17 276
1964—70	Metsämaa — *Forest land*	65.3	7.4	23.6	1.9	1.8	100.0	18 693



Kuva 2. Metsämaan omistus maan eri osissa.
Fig. 2. Forest land ownership in different parts of the country.

Taulukossa 8 on verrattu toisiinsa metsää kasvavan, so. lähinnä tuloveron alaisen metsäpinta-alan jakaantumista omistajittain 1960-luvun lopulla sekä V inventoinnin että tiedustelujen ja tilastointien tulosten perusteella. V inventoinnin tuloksista metsä- ja kitumaan summa on kutakuinkin yhtä suuri kuin veroluokkiin IA-V luettu pinta-ala.

Kun otetaan huomioon luokituksissa mahdolliset käsite-erot ja inventoinnin näytteellä saatujen tulosten satunnaisvirherajat, ovat eri tietä saadut tulokset varsin hyvin yhtäpitävät. Merkittävin ero on maan pohjoispuoliskossa yksityisen ja valtion omistuksen suhteissa. Eroa selittänee pääosaksi se, että inventoinnin tuloksissa valtion omistuksen kitumaahan sisältyy pinta-alaa, jota valtion omissa luokituksissa ei sisällytetä veronalaiseksi

Taulukko 8. Tiedusteluun perustuva metsää kasvavan maan omistus v. 1965 verrattuna V inventoinnin tulosten mukaiseen metsä- ja kitumaan omistukseen.

Table 8. Ownership of land growing forest in 1965 based on inquiries and compared with the ownership of forest and poorly productive land according to the results of the 5. inventory in 1964—70.

Alue *Area*	Menetelmä *Method*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*	
		%						1 000 ha
Eteläpuolisko	Tied. — *Inq.*	80.5	9.3	6.1	3.0	1.1	100.0	11 889
Southern half	Inv. — *Inv.*	79.7	10.1	6.8	2.4	1.0	100.0	11 888
Pohjoispuolisko	Tied. — *Inq.*	47.3	2.8	46.4	1.0	2.5	100.0	10 200
Northern half	Inv. — *Inv.*	42.4	3.1	50.6	1.0	2.9	100.0	10 478
Koko maa	Tied. — *Inq.*	65.1	6.3	24.7	2.1	1.8	100.0	22 089
Whole country	Inv. — *Inv.*	62.2	6.9	27.3	1.7	1.9	100.0	22 371

metsätalouden maaksi. Valtion metsien pinta-ala on myös jonkin verran pienentynyt 01.01.1965 kohdistuneen omistusselvityksen ja maan pohjoispuoliskossa vuosina 1969—70 suoritetun inventoinnin välisenä aikana.

Liitetaulukossa 1 on esitetty V inventoinnin tulosten mukainen metsänomistustilanne maaluokittain ja liitetaulukossa 2 kuvan 1 laskenta-alueittain. Taulukoiden ja myös kuvan 2 perusteella voidaan todeta, että metsän yksityisomistus on vahvinta maan länsi- ja eteläosissa, yhtiöiden omistus maan keski-, kaakkois- ja itäosissa sekä valtion omistus maan pohjoispuoliskossa. Yhteisömetsiä, pääasiassa yhteismetsiä on suhteellisesti eniten Pohjanmaalla ja maan pohjoispuoliskossa.

Maan tunnuksia omistajittain

Maan tunnuksista metsätalouden maa alaryhmittäin V inventoinnin tulosten perusteella on esitetty liitetaulukoissa 3 ja 4, kankaat kasvupaikkatyypeittäin liitetaulukoissa 5 ja 6 sekä taulukossa 9, metsätalouden maa veroluokittain liitetaulukoissa 7 ja 8 sekä soiden ojitustilanne inventoinnin ajankohtana taulukossa 10.

Metsämaan kankaiden viljavuutta eri omistajien osalla kuvaavista kasvupaikkatyyppien pinta-alatuloksista tehdyn yhdistelmän (Taulukko 9) ja myös edellä lueteltujen liitetaulukoiden mukaan yksityismetsissä maa on selvästi viljavampaa kuin muilla omistajilla. Heikoimmat maat ovat valtiolla ja sen jälkeen yhtiöillä. Nämä erot ovat vain korostuneet seurauksena itsenäisyyden aikana harjoitetusta maankäyttö- ja asutuspolitiikasta. Metsämaiden viljavuuden omistajittaisia eroja alueittain on esitetty kuvassa 3.

Taulukko 9. Metsämaan kankaat kasvupaikkatyyppiryhmittäin eri omistajilla 1964—70.

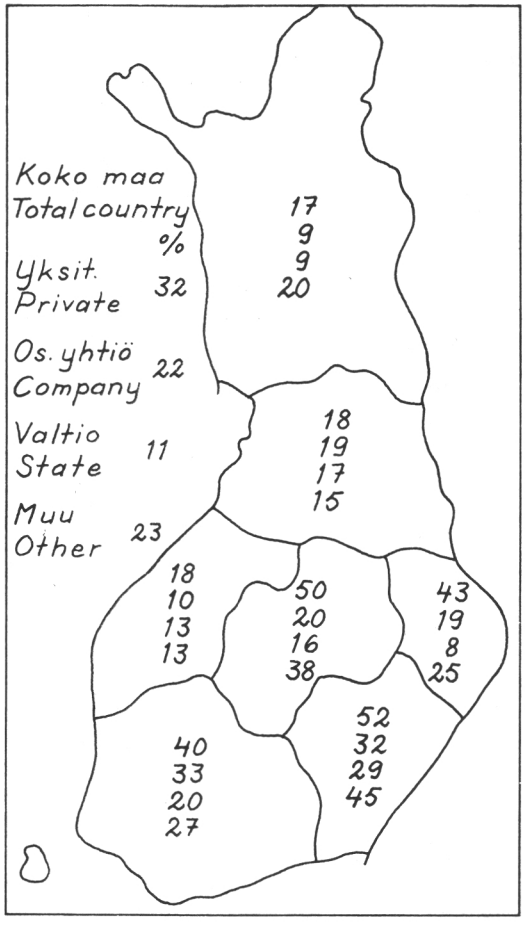
Table 9. Forest land on mineral soils by fertility classes and ownership categories in 1964—70.

Kankaiden luokat *Classes on mineral soils*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*
	% alasta — *% of area*					
	Eteläpuolisko — *Southern half*					
Lehdot ja lehtomaiset — *Rich sites*	27.4	10.0	4.6	21.3	15.9	24.1
Tuoreet — *Damp sites*	40.6	38.6	31.4	37.4	30.5	39.7
Kuivahkot ja huonommat — *Dry sites* ...	32.0	51.4	64.0	41.3	53.6	36.2
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	100.0
	Pohjoispuolisko — *Northern half*					
Lehdot ja lehtomaiset — *Rich sites*	4.2	2.5	2.0	3.3	2.7	2.8
Tuoreet — *Damp sites*	51.4	45.8	37.8	39.2	43.9	42.6
Kuivahkot ja huonommat — *Dry sites* ...	44.4	51.7	60.2	57.5	53.4	54.6
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	100.0
	Koko maa — *Whole country*					
Lehdot ja lehtomaiset — *Rich sites*	21.2	8.5	2.3	16.9	6.3	13.9
Tuoreet — *Damp sites*	43.5	40.0	37.2	37.8	40.3	41.1
Kuivahkot ja huonommat — *Dry sites* ...	35.3	51.5	60.5	45.3	53.4	45.0
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	100.0

Taulukko 10. Turvemaiden ja ojitusten määrä omistajittain maan etelä- ja pohjoispuoliskossa 1964—70.

Table 10. Peatland and peatland drainage area by ownership categories in Southern and Northern half of the country in 1964—70.

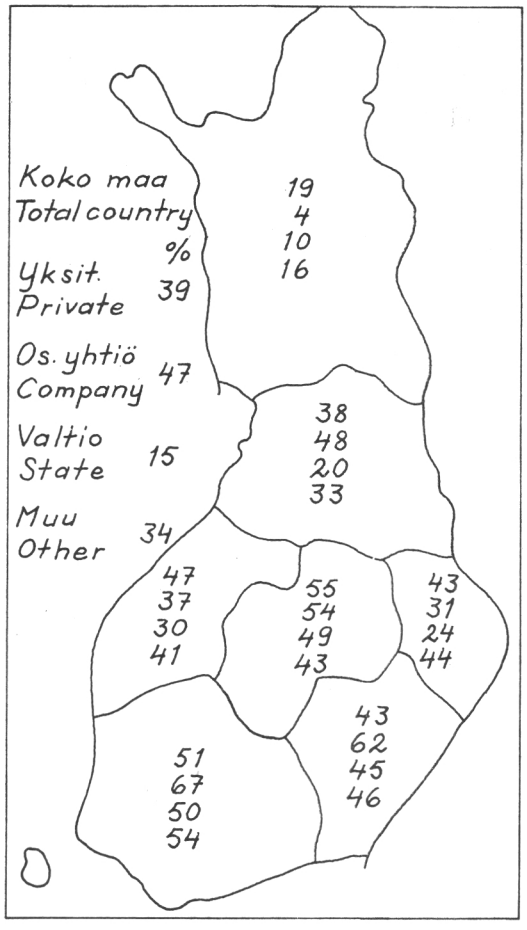
Turvemaan luokka *Peatland class*		Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*
		Eteläpuolisko — *Southern half, 1964—68*					
Turvemaata — *Peatland*	1 000 ha	2 931	447	425	86	69	3 958
	%	49	49	36	54	42	47
Ojitettu — *Drained*	1 000 ha	1 430	218	152	46	29	1 846
		Pohjoispuolisko — *Northern half, 1969—70*					
Turvemaata — *Peatland*	1 000 ha	2 823	178	2 649	52	119	5 821
	%	28	45	12	30	12	21
Ojitettu — *Drained*	1 000 ha	796	80	323	16	14	1 229
		Koko maa — *Whole country, 1964—70*					
Turvemaata — *Peatland*	1 000 ha	5 754	625	3 074	138	188	9 779
	%	39	47	16	45	22	32
Ojitettu — *Drained*	1 000 ha	2 226	298	475	62	43	3 104



Kuva 3. IA ja IB veroluokkien osuus metsätalouden maasta.
Fig. 3. Percentage of the two highest taxation site quality classes IA and IB of the total forestry land.

Soiden ojitus (Taulukko 10, Kuva 4, Liitetaulukot 9 ja 10) on edistynyt pisimmälle yhtiöiden, kuntien ja seurakuntien metsissä, kuitenkin niin, että maan eteläpuoliskossa yksityisten metsissä osuus on sama kuin yhtiöillä. Valtion metsissä ojitusten osuus on suhteellisesti vähäisin. Toisaalta valtiolla on suhteellisesti eniten soita ja myös eniten heikoimpia soita.

Koko turvemaan ala on 9.7 milj. ha ja siitä oli inventoinnin ajankohtana ojitettu 32 % eli 3.1 milj. ha. Kun otetaan huomioon, että vuotuinen ojitussaavutus on 1960-luvun lopulla ollut noin 290 000 ha, niin v. 1971 ojitettujen soiden määrä oli noin 4.3 milj. ha. Metsänparannusohjelmissa yleisesti esitetty ojitustavoite 7.0—7.5 milj. ha saavutetaan nykyisellä vauhdilla maan eteläpuoliskossa vajaassa 10 vuodessa ja pohjoispuoliskossa noin 15 vuodessa.



Kuva 4. Ojitetun pinta-alan osuus turvemaiden pinta-alasta 1964—70 inventoinnin kenttätyön ajankohtana.

Fig. 4. Proportion of area covered by drainage of the peatland area in 1964—70 at the time of the field work of the inventory.

Taulukko 11. Ojituksen edistyminen, prosenttia turvemaiden alasta.

Table 11. Progress of swamp drainage, percentage of peatland area.

	1936—38	1951—53	1964—70
	% turvemaan alasta—% *of peatland area*		
Eteläpuolisko — *Southern half*	4	18	47
Pohjoispuolisko — *Northern half*	△	4	21
Koko maa — *Whole country*	2	9	32

Turvekangasta ja muuttumaa on suhteellisesti eniten yksityisten, kuntien ja seurakuntien ojitetuilla alueilla, mikä johtuu siitä, että näissä metsissä ojitus on alkanut varhain ja usein maatalouden peruskuivatuksiin liittyen. Niinpä maan eteläpuoliskossa yksityisten turvemaista oli 8.4 % turvekankaita noin v. 1966.

Ojituksen edistymistä kuvaavan taulukon 11 mukaan pääosa ojituksista on tehty 1950-luvulla ja sen jälkeen. Eteläpuoliskossa maata oli jo sitäkin ennen saatu merkittäviä tuloksia aikaan.

PUUSTO

Puulajien vallitsevuus

Puulajien vallitsevuutta kuvaavat inventointitulokset kaikkien omistajien metsissä on esitetty taulukossa 12 ja eri omistajien metsissä liitetaulukoissa 11 ja 12. Jos jätetään aluemuutosten vaikutus huomioon ottamatta, niin kehitykselle on ollut leimaa antavaa havupuuvaltaisten metsiköiden lisääntyminen. Kuusikot ovat lisääntyneet luontaisen kuusettumisen, mutta myös hakkuutoiminnan ja kuusen viljelyn vuoksi. Männiköiden osuutta on taas suurentanut viimeaikainen männiköitä kuivilla mailla suosiva uudistaminen.

Tauluko 12. Puulajien vallitsevuus metsämaalla ja sen kehittyminen.
Table 12. Dominance of tree species on forest land and its development.

Puulaji *Tree species*	1921—24	1936—38	1951—53	1960—63	1964—70
	% metsämaan alasta % *of forest land area*				
	Eteläpuolisko — *Southern half*				
Mäntyvaltaisia — *Dominated by pine*	51.0	43.4	42.7	47.8	47.5
Kuusivaltaisia — *Dominated by spruce* ...	27.1	34.8	39.1	39.1	38.9
Koivuvaltaisia — *Dominated by birch*	16.6	18.1	15.5	9.4	8.0
Haapavaltaisia — *Dominated by aspen* ...	0.5	0.3	0.2	0.2	0.2
Leppävaltaisia — *Dominated by alder*	3.3	2.5	1.8	1.6	1.4
Puutonta — *Treeless*	1.5	0.9	0.7	1.9	4.0
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Pohjoispuolisko — *Northern half*				
Mäntyvaltaisia — *Dominated by pine*	54.5	54.3	59.1	62.9	66.7
Kuusivaltaisia — *Dominated by spruce* ...	31.2	32.3	30.1	24.3	22.1
Koivuvaltaisia — *Dominated by birch*	12.8	12.3	9.9	8.2	6.1
Haapavaltaisia — *Dominated by aspen* ...	0.0	0.1	0.1	0.1	0.1
Leppävaltaisia — *Dominated by alder*	0.1	0.1	0.1	0.1	0.1
Puutonta — *Treeless*	1.4	0.9	0.7	4.4	4.9
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Koko maa — *Whole country*				
Mäntyvaltaisia — *Dominated by pine*	53.0	48.4	49.7	54.5	55.5
Kuusivaltaisia — *Dominated by spruce* ...	28.6	33.3	35.3	32.5	32.0
Koivuvaltaisia — *Dominated by birch*	14.8	15.6	13.1	8.9	7.2
Haapavaltaisia — *Dominated by aspen* ...	0.3	0.2	0.1	0.2	0.1
Leppävaltaisia — *Dominated by alder*	1.8	1.6	1.1	0.9	0.9
Puutonta — *Treeless*	1.5	0.9	0.7	3.0	4.3
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0

Taulukko 13. Puulajien vallitsevuuden kehitys yksityisten, yhtiöiden ja valtion metsissä.

Table 13. Development of the tree species dominance in the private, company, and state forests.

Omistaja *Owner*	Puuton—*Treeless*			Mänty — *Pine*			Kuusi — *Spruce*			Lehtip.—*Dec.spp.*			Yht. *Total*
	1936 —38	1951 —53	1964 —70	1936 —38	1951 —53	1964 —70	1936 —38	1951 —53	1964 —70	1936 —38	1951 —53	1964 —70	
	% alasta — % *of area*												
	Eteläpuolisko — *Southern half*												
Yksityinen — *Private*	1.1	0.7	3.6	42.5	40.7	44.5	32.5	39.6	41.1	23.9	19.0	10.8	100.0
Osakeyhtiö — *Company*	0.5	0.6	5.2	45.3	48.7	59.7	38.3	31.4	31.6	15.9	19.3	3.5	100.0
Valtio — *State*	0.5	1.1	4.5	54.3	56.4	66.0	35.1	32.1	26.2	10.1	10.4	3.3	100.0
	Pohjoispuolisko — *Northern half*												
Yksityinen — *Private*	0.4	0.6	4.7	50.8	56.1	62.8	35.7	31.2	24.6	13.1	12.1	7.9	100.0
Osakeyhtiö — *Company*	0.1	1.6	6.5	44.8	51.4	73.8	45.9	39.6	16.3	9.2	7.4	3.4	100.0
Valtio — *State*	1.1	0.6	5.1	55.7	63.1	69.0	31.6	27.3	20.5	11.6	9.0	5.4	100.0
	Koko maa — *Whole country*												
Yksityinen — *Private*	1.0	0.7	3.9	44.1	44.7	49.7	33.1	37.4	36.4	21.8	17.2	10.0	100.0
Osakeyhtiö — *Company*	0.4	0.8	5.5	45.3	49.2	62.5	39.1	33.0	28.5	15.2	17.0	3.5	100.0
Valtio — *State*	0.8	0.7	5.0	55.5	62.2	68.5	32.3	27.9	21.4	11.4	9.2	5.1	100.0

Pinta-alallisesti eniten on pienentynyt koivuvaltaisten metsiköiden osuus, kuitenkin merkittävästi vasta viimeisten 20 vuoden aikana. Pitkäaikaisena kehityksenä leppä- ja haapavaltaisten metsien osuus on pienentynyt suhteellisesti yhtä paljon kuin koivuvaltaistenkin metsien määrä. Oleellinen muutos aikaisempiin aikoihin verrattuna on vielä 1950-luvulla lisääntyneen uudistustoiminnan aukeata uudistusalaa lisännyt vaikutus.

Tulevalle puulajisuhteiden kehittymiselle on todennäköisesti leimaa antavaa lehtipuuvaltaisten metsiköiden jatkuva väheneminen. Kuusikot lisääntyvät maan eteläpuoliskossa ja männiköt ennen muuta maan pohjoispuoliskossa.

Liitetaulukoissa 11 ja 12 on esitetty alueittaisia tietoja puulajien vallitsevuudesta eri omistajien metsissä. Puulajien vallitsevuus noudattaa kasvupaikkojen viljavuuden alueellista ja omistajittaista jakautumista, so. männiköitä on eniten siellä, missä on karuimmat maat. Lehtipuuvaltaisten metsiköiden pieni osuus yhtiöiden metsissä johtunee siellä toteutetusta johdonmukaisesta vajaatuottoisten metsiköiden uudistamisesta.

Taulukossa 13 on esitetty puulajisuhteiden kehittyminen II, III ja V inventoinnin tulosten mukaan yksityisten, yhtiöiden ja valtion metsissä. Uusien yksityistilojen perustamisesta johtuneiden pinta-alan muutosten vuoksi on vaikea päätellä, mikä vaikutus omistajalla on ollut kehitykseen.

Taulukko 14. Metsien ikärakenne ja sen kehittyminen.
Table 14. Distribution of age classes and its development.

Aika *Time*	Ikäluokka, v. — *Age class, y.*									Yhteensä *Total*
	Puuton *Treeless*	10	30	50	70	90	110	130	150+	
	% alasta — % *of area*									1 000 ha
	Eteläpuolisko — *Southern half*									
1921—24 ...	1.5	7.5	22.4	30.6	23.5	8.7	3.3	1.8	0.7	100.0	11 278
1936—38 ...	0.9	6.8	20.5	35.5	23.1	8.6	2.8	1.2	0.6	100.0	12 025
1951—53 ...	0.7	5.3	14.7	31.0	27.4	13.7	4.8	1.6	0.8	100.0	9 960
1960—63 ...	1.9	10.0	13.1	27.9	28.2	12.1	4.4	1.6	0.8	100.0	10 829
1964—70 ...	4.0	12.9	12.6	17.3	28.2	15.7	6.2	2.2	0.9	100.0	10 941
	Pohjoispuolisko — *Northern half*									
1921—24 ...	1.4	1.4	2.0	8.5	10.6	10.8	9.9	10.7	44.7	100.0	8 857
1936—38 ...	0.8	2.6	3.7	7.0	16.0	16.2	12.6	11.3	29.8	100.0	7 563
1951—53 ...	0.6	2.9	7.7	7.5	9.2	13.9	13.9	12.3	32.0	100.0	7 398
1960—63 ...	4.6	9.0	8.6	7.8	7.7	9.5	10.2	11.1	31.5	100.0	8 627
1964—70 ...	4.9	10.4	10.0	10.8	9.0	9.8	11.2	8.9	25.0	100.0	7 750
	Koko maa — *Whole country*									
1921—24 ...	1.5	4.8	13.4	20.9	17.8	9.6	6.2	5.7	20.1	100.0	20 135
1936—38 ...	0.9	5.2	14.0	24.5	20.3	11.5	6.6	5.1	11.9	100.0	19 588
1951—53 ...	0.6	4.3	11.7	21.0	19.6	13.8	8.7	6.2	14.1	100.0	17 358
1960—63 ...	3.1	9.6	11.1	19.0	19.1	10.9	7.0	5.8	14.4	100.0	19 456
1964—70 ...	4.4	11.9	11.5	14.6	20.2	13.2	8.3	5.0	10.9	100.0	18 691

Näyttää kuitenkin ilmeiseltä, että kuivien kankaiden kuusikoiden muuttaminen männiköiksi ja lehtipuuvaltaisten metsien vähentäminen on edistynyt nopeimmin yhtiöiden ja toiseksi nopeimmin valtion metsissä.

Ikärakenne

Metsien ikärakenne ja sen kehittyminen on kuvattu taulukoissa 14 ja 15 ja kuvassa 5 sekä suurimpien omistajien metsissä taulukossa 16 ja kuvissa 6 a, b ja c. Liitetaulukoissa 13 ja 14 on lisätietoja ikärakenteesta alueittain.

Ikärakenteen tärkeimpiä piirteitä 1920-luvulla olivat nuorien ja keskiikäisten metsiköiden runsaus maan eteläpuoliskossa ja vanhojen metsiköiden runsaus pohjoispuoliskossa. Aluksi hakkuut olivat luonteeltaan pääasiassa tukkirunkojen poimintaa ja vanhimpien metsiköiden korjuuta. Vanhimpien metsiköiden osuus pieneni ja puusto nuoreni pääosaksi alikasvosten vapautumisen ja kuusen lisääntymisen johdosta.

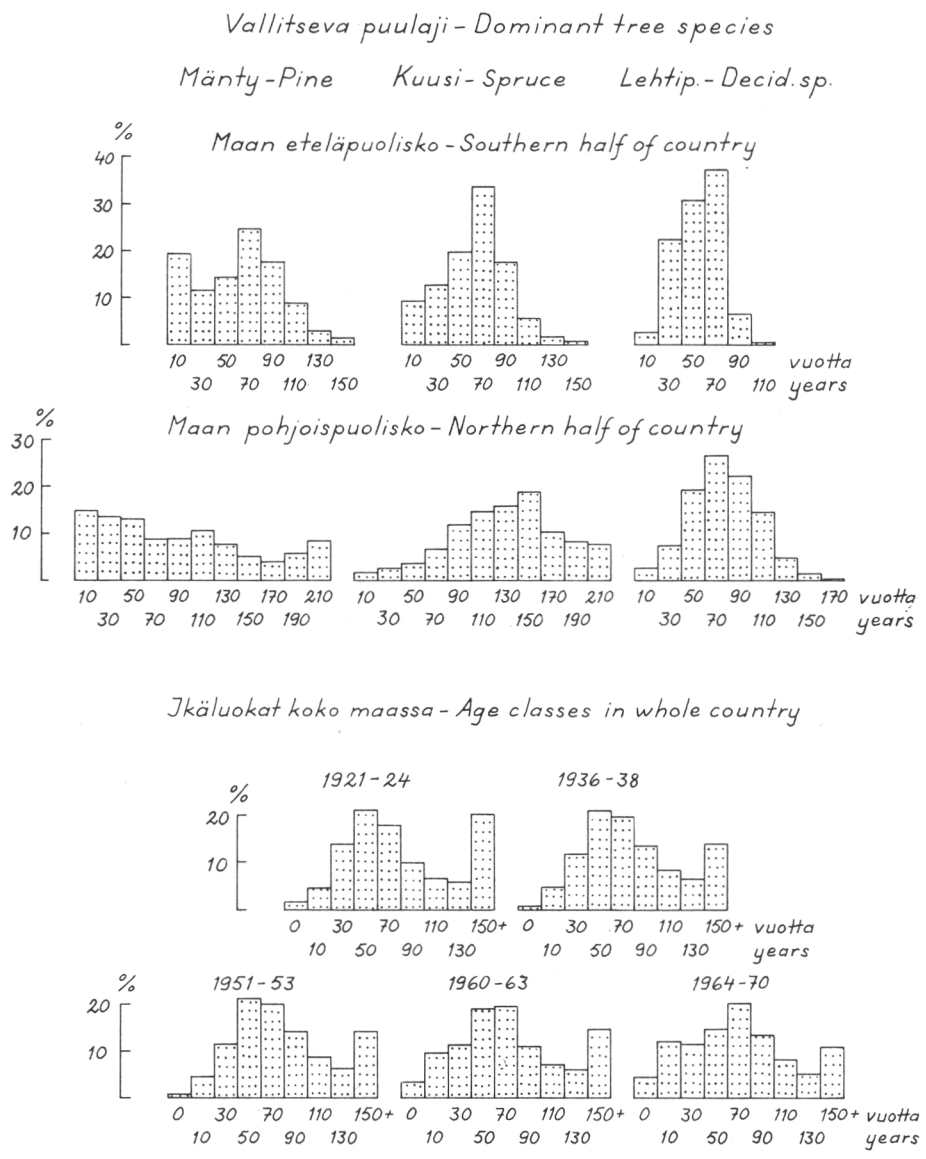
Puutavaran menekkiolojen muututtua siten, että pinotavaralle tuli pysyvä kysyntä, alaharvennukset yleistyivät. Samanaikaisesti 1950-luvulla yleistyi myös metsiköiden uudistaminen aukean alan ja taimiston kautta.

Taulukko 15. Mänty-, kuusi- ja lehtipuuvaltaisten metsiköiden ikärakenne 1964—70.
Table 15. Age structure of stands dominated by pine, spruce and deciduous species in 1964—70.

Alue *Area*	Vallitseva puulaji *Dominant tree species*	Ikäluokka, vuotta — *Age class, years* 10	30	50	70	90	110	130	150	170	190	210+	Yhteensä *Total*
		% alasta — % *of area*											1 000 ha
Eteläpuolisko *Southern half*	Mänty — *Pine*	19.1	11.6	14.2	24.5	17.7	8.6	3.0	1.3				100.0	5 198
	Kuusi — *Spruce*	9.2	12.7	19.7	33.3	17.3	5.3	1.7	0.8				100.0	4 257
	Lehtipuut — *Dec. species* ..	2.9	22.3	30.9	37.1	6.3	0.5	0.0					100.0	1 051
Pohjoispuolisko *Northern half*	Mänty — *Pine*	14.6	13.4	13.1	8.8	8.7	10.5	7.6	5.2	4.0	5.9	8.2	100.0	5 165
	Kuusi — *Spruce*	1.7	2.4	3.3	6.7	11.7	14.5	15.7	18.3	10.0	8.0	7.7	100.0	1 720
	Lehtipuut — *Dec. species* ..	2.6	7.3	19.1	26.6	22.1	14.6	4.9	1.4	1.2	0.2		100.0	493
Koko maa *Whole couniry*	Mänty — *Pine*	16.9	12.5	13.6	16.6	13.2	9.5	5.3	3.3	2.0	3.0	4.1	100.0	10 363
	Kuusi — *Spruce*	7.1	9.7	15.0	25.6	15.7	8.0	5.7	5.8	2.9	2.3	2.2	100.0	5 977
	Lehtipuut — *Dec. species* ..	2.8	17.5	27.1	33.7	11.3	5.0	1.6	0.5	0.4	0.1		100.0	1 544

Taulukko 16. Ikärakenteen kehitys yksityisten, yhtiöiden ja valtion metsissä.
Table 16. Development of the age structure in the private, company and state forests.

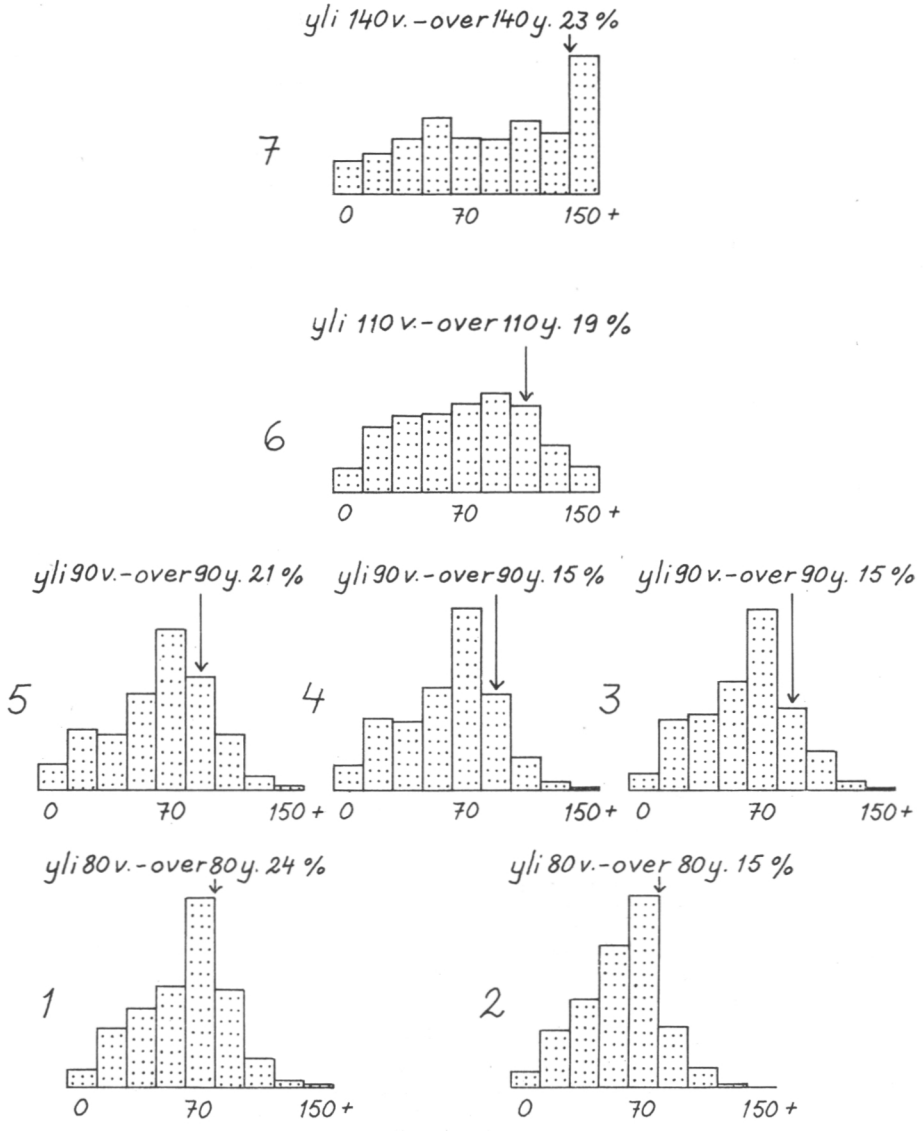
Omistaja *Owner*	1—20 v.—*y.* 1936—38	1951—53	1964—70	21—40 v.—*y.* 1936—38	1951—53	1964—70	41—80 v.—*y.* 1936—38	1951—53	1964—70	81—120 v.—*y.* 1936—38	1951—53	1964—70	121 + v.—*y.* 1936—38	1951—53	1964—70
	% alasta — % *of area*														
	Eteläpuolisko — *Southern half*														
Yksityinen — *Private*	6.3	5.0	10.7	23.5	15.4	12.4	61.5	62.1	49.5	7.1	15.7	21.7	0.5	1.1	2.3
Osakeyhtiö — *Company*	7.8	5.3	24.6	14.3	11.4	11.6	60.0	52.2	32.5	16.5	27.6	23.0	0.9	2.8	3.1
Valtio — *State*	7.8	8.4	22.4	7.2	11.7	12.5	41.9	27.4	23.0	31.0	36.5	22.9	11.6	14.9	14.7
	Pohjoispuolisko — *Northern half*														
Yksityinen — *Private*	2.7	2.9	9.0	6.1	9.9	11.4	38.5	28.8	25.2	32.1	34.0	26.6	20.2	23.8	23.1
Osakeyhtiö — *Company*	0.7	4.2	25.1	4.6	6.7	13.1	46.7	20.6	17.0	40.7	47.3	29.5	7.2	19.6	8.8
Valtio — *State*	2.5	2.8	10.6	2.5	6.2	8.6	14.5	8.8	15.1	27.8	22.5	15.3	51.6	59.1	45.4
	Koko maa — *Whole country*														
Yksityinen — *Private*	5.6	4.4	10.2	19.9	14.0	12.1	56.8	53.4	42.5	12.2	20.5	23.1	4.5	7.0	8.2
Osakeyhtiö — *Company*	7.1	5.1	24.7	13.4	10.5	11.9	58.7	46.2	29.4	18.9	31.4	24.3	1.5	6.0	4.2
Valtio — *State*	3.6	3.5	12.5	3.4	6.9	9.2	19.9	11.1	16.4	28.5	24.3	16.5	43.8	53.5	40.3



Kuva 5. Ikärakenne mänty-, kuusi- ja lehtipuuvaltaisissa metsissä 1964—70 ja koko puuston ikärakenteen kehittyminen 1920—70.

Fig. 5. Age structure of the forests dominated by pine, spruce and deciduous species in 1964—70 and the development of the age structure of all forests in 1920—70.

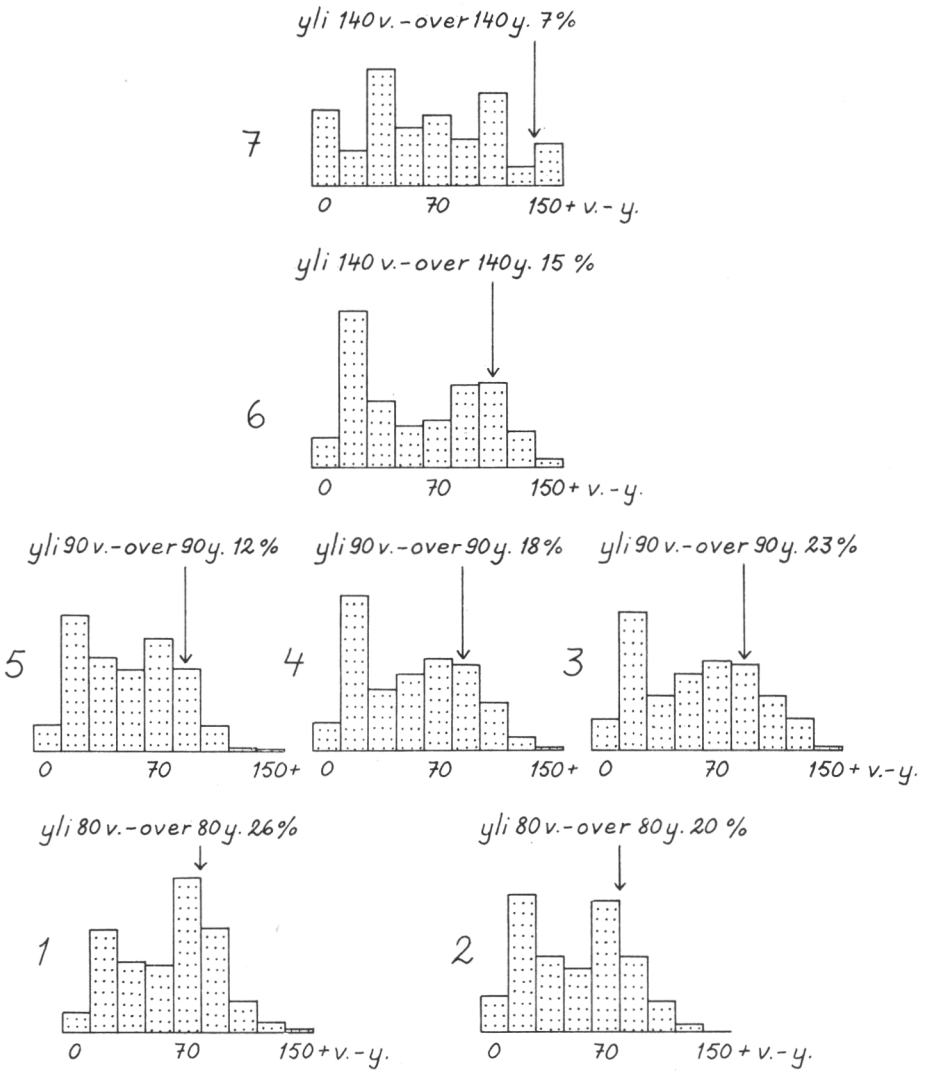
1960-luvun lopulla maan eteläpuoliskossa runsain ikäluokka käsittää 61—80 vuotiaita metsiköitä. Pohjoispuoliskossa on vanhimpien metsiköiden osuus voimakkaasti vähentynyt. Taimistoja on ilmaantunut runsaasti ja niistä eniten mäntyvaltaisia.



Kuva 6a. Ikärakenne yksityismetsissä maan eri osissa (Vert. kuva 1).
Fig. 6a. Age structure of the private forests in different parts of the country (Comp. Fig. 1).

Kokonaisuutena korjuukypsiä ja sitä lähestyviä metsiköitä on runsaasti. Lähiajan päätekorjuumahdollisuudet ovat hyvät ja ne paranevat jatkuvasti.

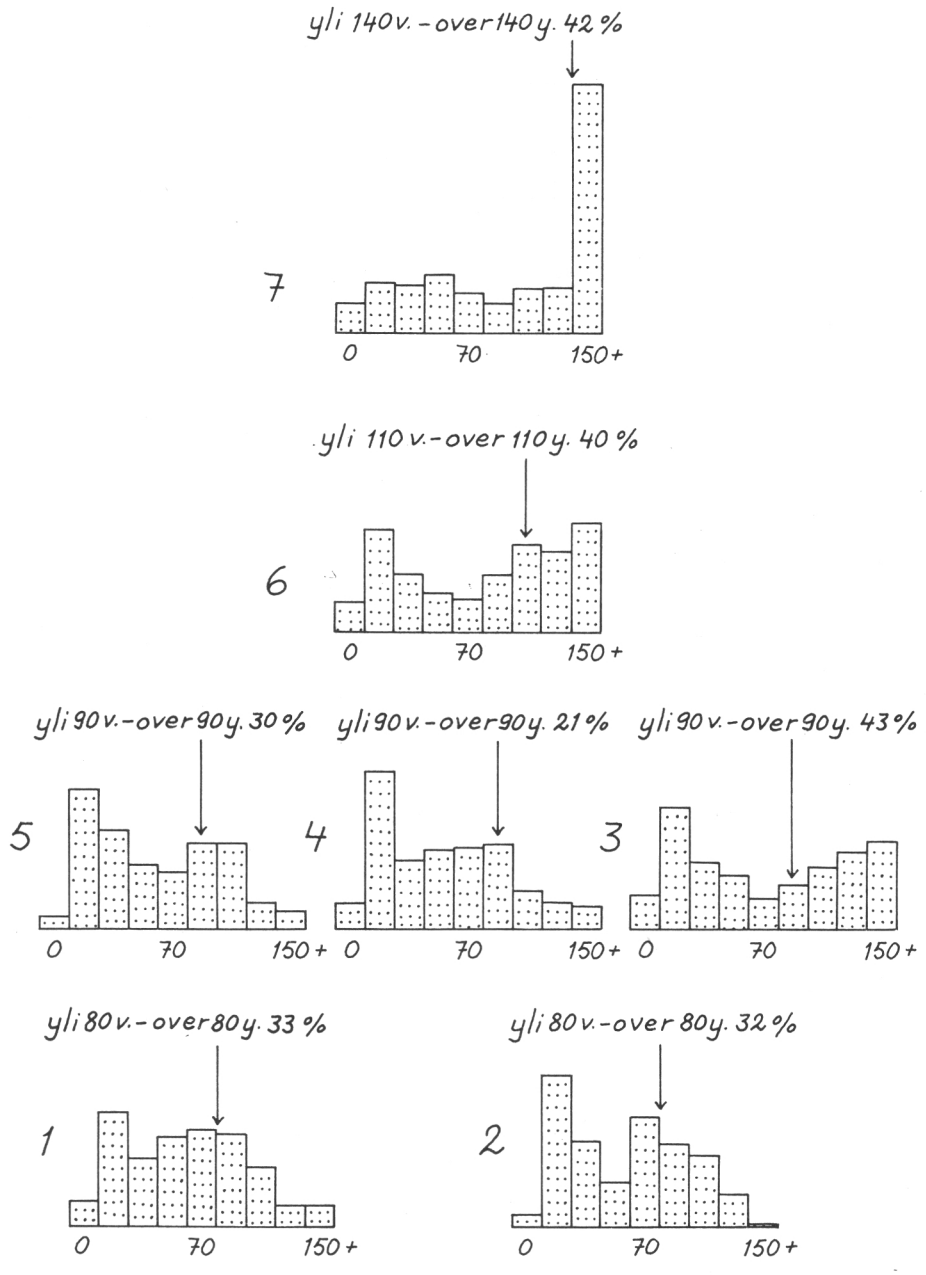
Suurimpien omistajien metsissä ikärakenteen kehittymistä kuvaavat inventoinnin tulokset (Taulukko 16) osoittavat, että uudistaminen on ollut suhteellisesti voimakkainta yhtiöiden ja valtion metsissä, erityisesti maan itä- ja pohjoisosissa.



Kuva 6b. Ikärakenne yhtiöiden metsissä maan eri osissa (Vert. Kuva 1).
Fig. 6b. Age structure of the company forests in different parts of the country (Comp. Fig. 1).

Metsien suhteellinen vanheneminen on ollut voimakkainta yksityismetsissä. Ikärakennetietoja verrattaessa on kuitenkin syytä ottaa huomioon, että yhtiöiden ja valtion metsissä on alun perin ollut enemmän vanhoja metsiköitä kuin yksityismetsissä.

Ikärakennetietojen perusteella ja erityisesti taimistojen osuus huomioon ottaen voidaan päätellä, että yksityismetsissä varsinkin maan etelä-, lounais- ja länsiosissa ei ole käytetty kaikkia kestäviä hakkuumahdolli-



Kuva 6c. Ikärakenne valtion metsissä maan eri osissa (Vert. Kuva 1).
Fig. 6c. Age structure of the state forests in different parts of the country (Comp. Fig. 1).

suuksia hyväksi. Metsiköitä on kasautumassa yli-ikäistyvään vaiheeseen (Kuvat 6 a, b ja c). Maan eteläpuoliskon yksityismetsissä on yli 80 vuo-

tiaiden metsiköiden osuus 22 % ja 41—80 vuotiaiden osuus 50 %. Yhtiöiden ja myös valtion metsissä runsaiden taimistoluokkien perusteella voi päätellä, että niissä on kestävä hakkuumäärä ylitetty 1950- ja 60-luvulla.

Valtion metsien ikärakenteessa on syytä kiinnittää huomiota keski-ikäisten metsiköiden pieneen määrään varsinkin Pohjois-Karjalassa, Pohjois-Pohjanmaalla, Kainuussa ja Perä-Pohjolassa. Ikärakenne on seurausta aikaisemmasta metsien yli-ikäistymisestä. Näin muodostunutta vanhojen metsiköiden kasautumaa riittää jatkuvasti purettavaksi. Vaikka valtion metsissä on vielä päätekorjuumahdollisuuksia runsaasti, on niiden kasvu pieni. Kestävän suunnitteen noudattamisesta on seurauksena vanhojen puustojen seisottamista ja suuri luonnonpoistuma etenkin Perä-Pohjolassa. Vaikka valtion metsien nykytila johtuukin pääosaksi huonoissa menekkioloissa tapahtuneesta metsien yli-ikäistymisestä ja osaksi valtion omistukselle usein ominaisesta passiivisesta metsän käsittelystä, se osoittaa, että puuston yli-ikäistyminen johtaa metsätalouden pitkäaikaiseen tuotannon aallonpohjaan.

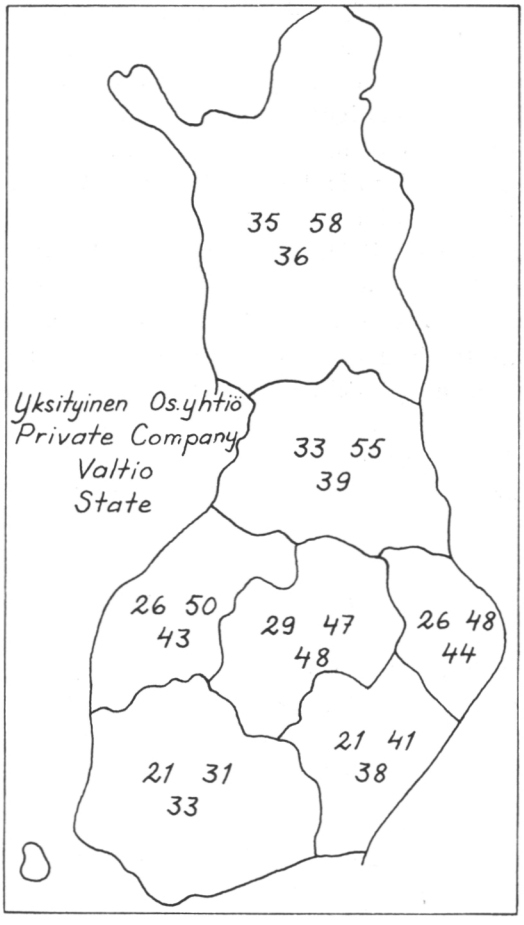
Kehitysluokkarakenne

Metsiköiden kehitysluokkiin jakaantumista kuvaavat tiedot maan eri osissa ja omistajittain on esitetty liitetaulukoissa 15 ja 16 sekä kehitysluokkaryhmittäin suurimpien omistajien metsissä taulukossa 17. Kehitysluokkarakenteen tärkeimpiä piirteitä valaisevat myös kuvat 7 ja 8.

Taulukko 17. Kehitysluokkaryhmät yksityisten, osakeyhtiöiden ja valtion metsissä 1964—70.

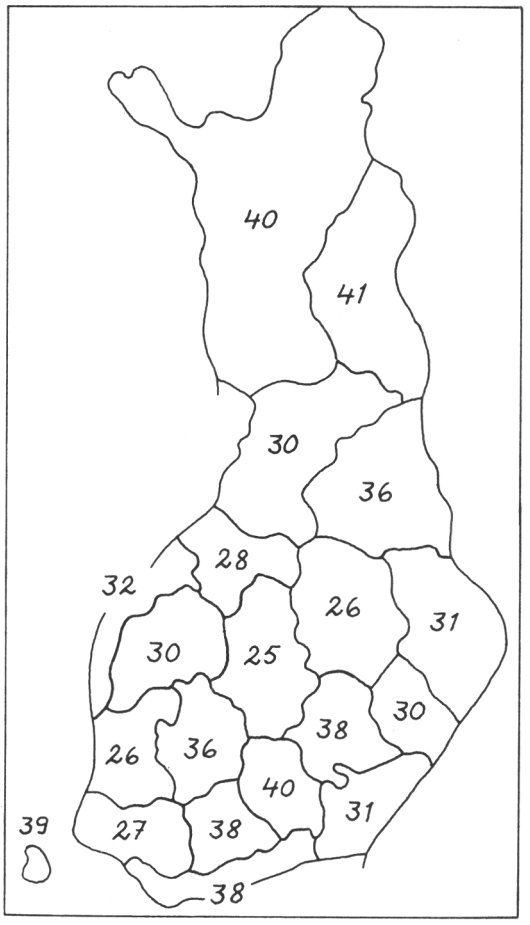
Table 17. Development class groups in private, company and state forests in 1964—70.

Kehitysluokka *Development class*	Eteläpuolisko *Southern half*			Pohjoispuolisko *Northern half*			Koko maa *Whole country*		
	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*
	% alasta — % *of area*								
Uudistusala, taimisto, riukuvaihe — *Reg. area, seedling and sapling stand*	23.5	43.0	41.1	34.5	55.4	35.2	26.6	45.5	36.2
Kasvatusmetsikkö — *Thinning stand*	44.0	34.5	27.7	30.8	24.4	20.6	40.3	32.6	21.8
Uudistuskypsä — *Mature* ..	32.5	22.5	30.4	34.7	20.2	44.0	33.1	21.9	41.7
Luonnonsuojelualue — *Nature conservation area*			0.8			0.2			0.3
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Vajaatuottoinen — *Low-yielding*	15.1	5.3	9.2	16.5	7.1	17.5	15.5	5.6	16.1



Kuva 7. Uudistusalan, taimisto- ja riukuvaiheen metsiköiden yhteinen osuus % metsämaan alasta yksityisten, osakeyhtiöiden ja valtion metsissä.
Fig. 7. Proportional area percentage of regeneration areas, seedling and sapling stand from forest land area in private, company and state forests.

Metsiköiden kehitysluokkien osuudet kuvaavat monia sellaisia metsien ominaisuuksia, joita on tullut esille jo ikärakennetietojen yhteydessä. Jos otetaan ohjeeksi hakkuulaskelmien tulos, jonka mukaan metsien ikärakenteesta ja suoritetuista perusparannuksista riippuen kestävät korjuumahdollisuudet on käytetty täysin hyväksi, kun uudistusalan, taimisto- ja riukuvaiheen osuus on 27—30 %, niin voidaan todeta, että maan eteläpuoliskon yksityismetsissä, lukuun ottamatta Keski-Suomen, Pohjois-Savon ja Pohjois-Karjalan pohjoisosia, kestäviä hakkuumahdollisuuksia ei ole kaikkia käytetty hyväksi. Maan lounaisosan yhtiöiden metsissä korjuu



Kuva 8. Uudistuskypsien, suojuspuu- ja vajaatuottoisten metsiköiden yhteinen osuus % metsämaan alasta piirimetsälautakuntien alueilla.
Fig. 8. Proportional area percentage of mature, shelter wood and lowyielding stands from forest land area in forestry board districts.

näyttäisi olleen kutakuinkin kestävän hakkuumäärän suuruinen. Muualla yhtiöiden ja valtion metsissä viimeaikainen korjuu on ollut kestävyyden ylittänyttä. Valtion metsissä tilanteeseen on kuitenkin vaikuttanut korjuukypsien metsien myöhään jatkunut siirto asutuksen kautta yksityisomistukseen. Perä-Pohjolan ja myös Kainuun yksityismetsissä näyttäisi metsänkäyttö ylittäneen kestävän hakkuumäärän.

Kuten jo ikärakennetietojen yhteydessä todettiin, lähimpien 20 vuoden aikana on uudistuskypsiä metsiköitä runsaasti, mikä on todettavissa myös kuvasta 8. Uudistuskypsien, suojuspuu- ja vajaatuottoisten metsiköiden

kuutiomäärä on noin 40 % kokonaiskuutiomäärästä. Myös maan itä- ja pohjoisosissa on runsaasti uudistuskypsiä metsiköitä, joiden uudistamisen nopeutta rajoittaa kuitenkin keski-ikäisten metsiköiden vähäisyys. Valtion jäljellä olevien vanhojen metsiköiden korjaamista ja uudistamista rajoittaa vielä niiden sijainti pohjoisessa pitkien kuljetusmatkojen takana ja hitaasti uudistuvilla alueilla. Tarve perustaa uusia laajoja luonnonsuojelualueita rajoittaa myös valtion metsien käyttöä puun tuotantoon. Kaikki nämä tekijät yhdessä merkinnevät sitä, että puun korjuu valtion metsistä pienenee voimakkaasti 1960-luvun määristä.

Vajaatuottoisten puustoa sisältävien metsiköiden osuuksien perusteella on pääteltävissä, että yhtiöiden metsissä ja myös maan eteläpuoliskon valtion metsissä on pyritty määrätietoisesti uudistamaan vajaatuottoisia metsiköitä. Pohjoispuoliskon valtion metsissä vajaatuottoisten metsiköiden suuri osuus johtuu pääosaksi yli-ikäisten metsien runsaudesta.

Kuntien, seurakuntien ja yhteisöjen metsien kehitysluokkarakennetta valaisevat tiedot ovat alueiden pienuudesta ja satunnaisvirheiden mahdollisuudesta johtuen suhteellisen epävarmoja (Liitetaulukot 15 ja 16). Yleensä näissä metsissä on käytetty hyväksi kestävyyden sallimat päätehakkuumahdollisuudet. Pohjoispuoliskossa yhteisöjen metsissä on päätehakkuukypsien metsiköiden kasautuma, noin 50 % pinta-alasta, joka johtuu siitä, että uusia yhteismetsiä muodostettaessa niihin on siirretty runsaasti suurikuutioisia vanhoja valtion metsiä.

Ikä- ja kehitysluokkataulukoiden perusteella on pääteltävissä, että vahvan päätehakkuutoiminnan alueet sijoittuvat Pohjois-Karjalan, Pohjois-Savon ja Keski-Suomen pohjoisosiin, Kainuuseen ja Lappiin, ts. alueille, joissa on keskimääräistä enemmän valtion ja yhtiöiden metsiä ja joissa maaseutuväestön työn ja tulojen tarve on edellyttänyt vahvaa hakkuutoimintaa. Tämä on ollut mahdollista myös sen vuoksi, että näillä alueilla on ollut ja on yhä runsaasti vanhoja ja yli-ikäisiä metsiköitä.

Kuutiomäärä

Puuston kuutiomäärän arvio V inventoinnin tulosten mukaan on esitetty taulukossa 18. Taulukon tiedoista on syytä kiinnittää huomiota kitumaan puuston suhteellisen pieneen osuuteen maan eteläpuoliskossa, jossa se on 1 % kokonaiskuutiomäärästä. Kitumaan puusto on valtaosaltaan mäntyä. Ojitustoiminnalla muutettaneen huomattava osa eteläpuoliskon soista, joita on 734 000 ha ja jotka käsittävät valtaosan eteläpuoliskon kitumaasta (Taulukot 2 ja 3), metsämaaksi, joten kitumaan puuston suhteellinen osuus pienenee nykyisestäänkin.

Taulukko 18. Kuutiomäärä kuorineen ja kuoriprosentti 1964—70.
Table 18. Growing stock volume, incl. bark and bark percentage in 1964—70.

Puulaji *Tree species*	Metsämaalla *On forest land*		Kitumaalla *On poorly prod.land*		Yhteensä *Total*		Kuoriprosentti *Bark percentage*
	Milj. m³ *Mill. m³*	%	Milj. m³ *Mill. m³*	%	Milj. m³ *Mill. m³*	%	
	Eteläpuolisko — *Southern half*						
Mänty — *Pine*	378	97	11	3	389	100	16.1
Kuusi — *Spruce*	413	100	1	△	414	100	15.5
Lehtipuut — *Dec. species*	190	99	2	1	192	100	16.2
Yhteensä — *Total*	981	99	14	1	995	100	15.8
	Pohjoispuolisko — *Northern half*						
Mänty — *Pine*	226	92	20	8	246	100	16.3
Kuusi — *Spruce*	119	95	6	5	125	100	16.4
Lehtipuut — *Dec. species*	73	89	9	11	82	100	18.4
Yhteensä — *Total*	418	92	35	8	453	100	16.7
	Koko maa — *Whole country*						
Mänty — *Pine*	604	95	31	5	635	100	16.1
Kuusi — *Spruce*	532	99	7	1	539	100	15.7
Lehtipuut — *Dec. species*	263	96	11	4	274	100	16.8
Yhteensä — *Total*	1 399	97	49	3	1 448	100	16.1

Maan pohjoispuoliskossa kitumaan puustolla, joka inventoinnin ajankohtana käsitti 8 % kokonaiskuutiosta, on sen sijaan pysyvästi merkittävä osuus puuston kuutiomäärästä. Kitumaan puuston osuus suurenee pohjoiseen siirryttäessä ja Lapin piirimetsälautakunnan alueella se on 11 %. Pohjois-Suomessa niin kitumaan soilla kuin tuntureillakin on merkittävästi myös koivua. Kitumaan puuston suurella osuudella pohjoisessa on sikäli merkitystä, että sen korjaaminen on kallista ja että laajoilla alueilla se jäänee teollisuuspuun korjuun ulkopuolelle.

Puuston kuutiomäärä puulajeittain ja kuutiomäärän sekä puulajien osuuksien kehittyminen inventointien tulosten mukaan on esitetty taulukossa 19 ja kuvassa 9. Jos rajoitutaan Suomen nykyiseen pinta-alaan, niin voidaan todeta, että puuston kuutiomäärä oli suurimmillaan 1950-luvun alussa, jolloin metsässä oli kasvun kannalta edullisen ikärakennevaiheen ja sodanaikaisten hakkuusäästöjen seurauksena runsas puusto. IV inventoinnin tulos vuosilta 1960—63 ei ole täysin vertailukelpoinen muiden arvioiden kanssa sen vuoksi, että siitä puuttuu osa kitumaan puustoa. 1950-luvun jälkeen puuston kuutiomäärä V inventoinnin tuloksen mukaan on pienentynyt 3.0 % koko maassa, maan eteläpuoliskossa suurentuminen on 1.5 % ja pohjoispuoliskossa pienentyminen 11.7 %. Ottamalla huomioon satunnaisvirheen mahdollisuus voidaan todeta, että eteläpuoliskossa puuston kuutiomäärä on säilynyt likimain ennallaan ja pohjoispuoliskossa samoin koko

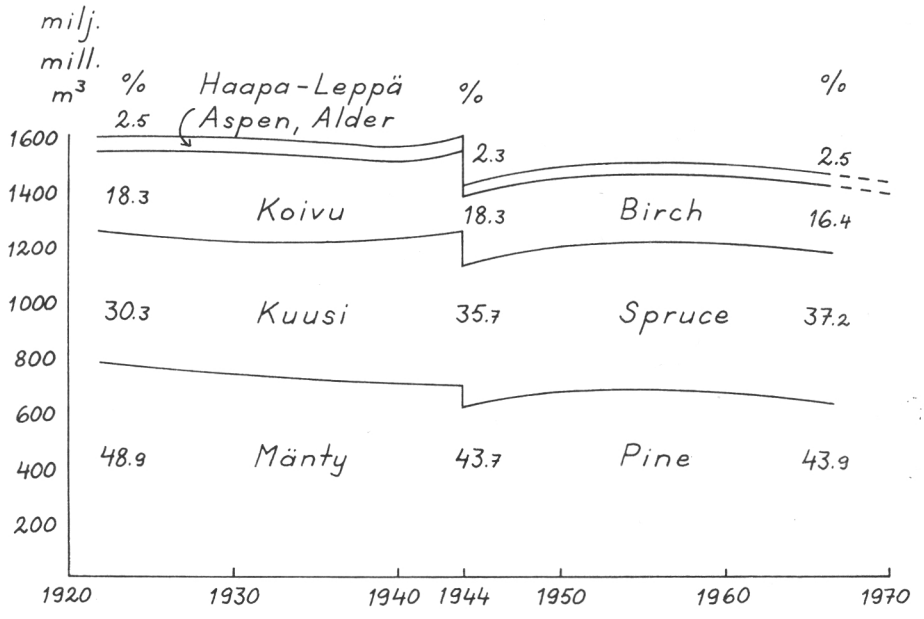
Taulukko 19. Puulajien osuudet kuutiomäärästä ja niiden kehittyminen.
Table 19. Proportions of the tree species in the growing stock volume and their development.

Puulaji *Tree species*	1921—24[1])	1936—38[1])	1951—53[2])	1960—63	1964—70	1964—70 Milj. m³ Mill.
	% kuutiomäärästä — % *of volume*					
	Eteläpuolisko — *Southern half*					
Mänty — *Pine*	48.4	42.8	40.0	38.6	39.2	389
Kuusi — *Spruce*	28.4	33.2	38.6	41.6	41.6	414
Koivu — *Birch*	19.5	19.3	18.8		16.3	162
Haapa — *Aspen*	1.9	2.2	1.2	19.8	1.2	12
Leppä — *Alder*	1.8	2.5	1.4		1.7	17
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	
Kuutiomäärä, milj. m³ — *Volume mill. m³*	1 048	1 026	980	957	995	995
	Pohjoispuolisko — *Northern half*					
Mänty — *Pine*	50.0	50.0	50.9	52.1	54.3	246
Kuusi — *Spruce*	33.9	30.3	30.2	29.7	27.5	125
Koivu — *Birch*	15.9	18.2	17.3		16.5	75
Haapa — *Aspen*	0.2	1.3	1.2	18.2	1.4	6
Leppä — *Alder*		0.2	0.4		0.3	1
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	
Kuutiomäärä, milj. m³ — *Volume, mill. m³*	540	534	513	453	453	453
	Koko maa — *Whole country*					
Mänty — *Pine*	48.9	45.3	43.7	43.0	43.9	635
Kuusi — *Spruce*	30.3	32.2	35.7	37.6	37.2	539
Koivu — *Birch*	18.3	18.9	18.3		16.4	238
Haapa — *Aspen*	1.3	1.9	1.2	19.4	1.3	18
Leppä — *Alder*	1.2	1.7	1.1		1.2	18
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	
Kuutiomäärä, milj. m³ — *Volume, mill. m³*	1 588	1 560	1 493	1 410	1 448	1 448

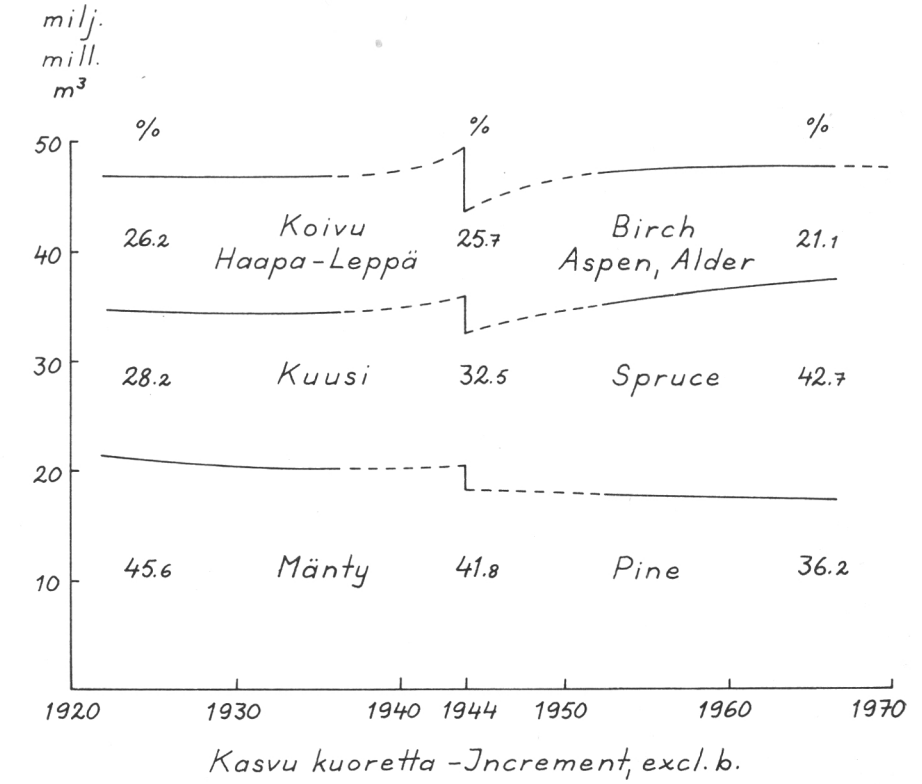
[1]) Pinta-ala ennen v. 1940. — *Area before 1940.*
[2]) Pinta-ala v. 1944. — *Area in 1944.*

maassa on tapahtunut merkitsevää pienenemistä. Pohjoispuoliskossa pieneneminen on tapahtunut Koillis-Suomen, Lapin ja Kainuun piirimetsälautakuntien alueella.

Kuutiomäärän puulajiosuuksien pitkäaikaiselle kehittymiselle on ominaista männyn osuuden pieneneminen, jonka mäntyä suosiva uudistustoiminta voi tulevaisuudessa pysähdyttää, kuusen osuuden suureneminen, jota jo ilmeisestikin hidastaa kuusen väheneminen maan pohjoispuoliskossa, ja lehtipuiden osuuden pieneneminen, joka todennäköisesti on kiihtyvää. Maan eteläpuoliskossa on kuusesta tullut jo kuutiomääräosuudella mitattuna pääpuulaji ja se tulee nykynäkymien mukaan vahvistamaan asemaansa lähinnä lehtipuiden kustannuksella. Pohjoispuoliskossa on männystä kehittymässä entistä selvemmin pääpuulaji.

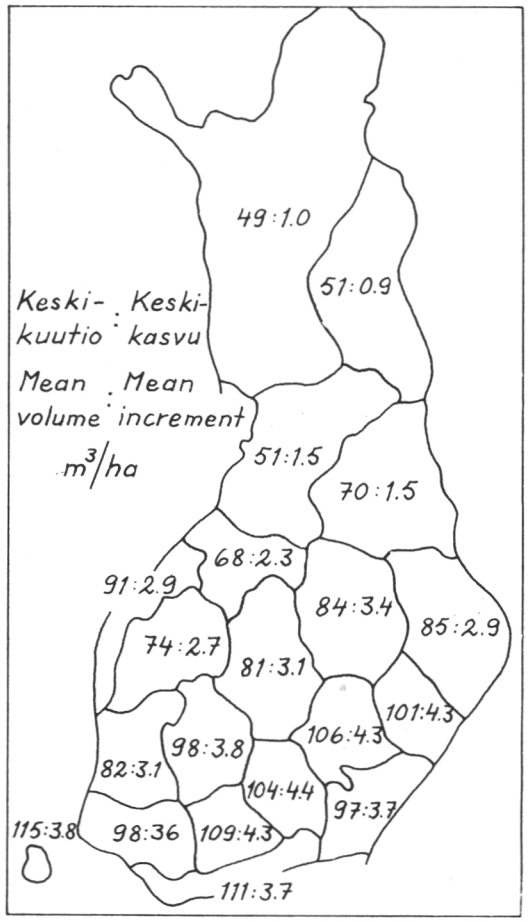


Puuston kuorellinen kuutiomäärä - Growing stock volume, incl. b.



Kasvu kuoretta - Increment, excl. b.

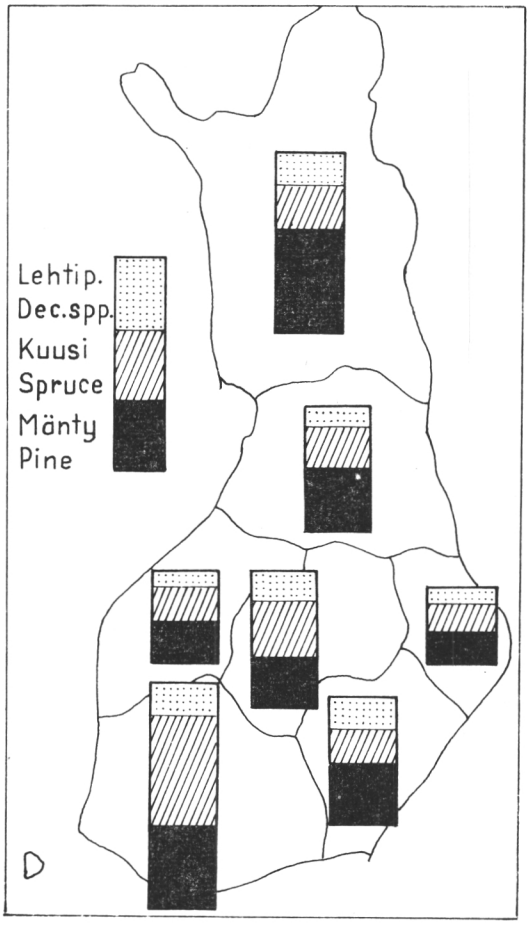
Kuva 9. Puuston kuutiomäärän, kasvun ja puulajien osuuksien kehittyminen 1920—70.
Fig. 9. Development of the growing stock volume, increment and tree species proportions 1920—70.



Kuva 10. Keskikuutio kuorineen ja keskikasvu kuoretta metsämaan hehtaaria kohti piirimetsälautakuntien alueilla.
Fig. 10. Mean volume, incl. bark, and mean increment, excl. bark, on forest land hectare by forestry board districts.

Lehtipuista leppä ja myös haapa ovat sitkeästi säilyttäneet osuuttaan. Tämä selittynee vain sillä, että nämä puulajit metsittävät maataloudesta metsätalouden puolelle siirtyviä laitumia ja nykyisin myös peltoja.

Puuston ja puulajien kuutiomäärän alueellinen jakaantuminen on esitetty taulukossa 20 ja kuvassa 11. Puuston kuutiomäärä ja kuusivarat ovat painottuneet maan lounaisosaan. Kun vielä otetaan huomioon, että samalla alueella on pääosa parhaista pelloista, niin maa- ja metsätalouden luonnonvarat ovat suhteellisesti runsaimmat vauraimmassa ja teollistuneimmassa osassa Suomea. Huonolaatuisen lehtipuun suhteellisen suuri osuus Perä-Pohjolassa on merkittävä vajaatuottoisuutta lisäävä tekijä.



Kuva 11. Puuston ja puulajien kuutiomäärän alueellinen jakaantuminen.
Fig. 11. Volume of the growing stock and tree species by areas.

Taulukko 20. Puuston ja puulajien kuutiomäärän jakaantuminen 7 laskenta-alueelle (Kuva 1).
Table 20. Growing stock and tree species volume by 7 calculation areas (Fig. 1).

Puulaji *Tree species*	Laskenta-alue — *Calculation area*							
	1	2	3	4	5	6	7	Yhteensä *Total*
	% kuutiomäärästä — % *of volume*							
Mänty — *Pine*	19.3	13.0	7.7	11.2	10.1	15.1	23.6	100.0
Kuusi — *Spruce*	30.6	11.1	6.7	18.4	10.0	10.8	12.4	100.0
Lehtip. — *Dec. spp.*	18.7	18.0	9.5	15.0	8.8	11.0	19.0	100.0
Yhteensä — *Total*	23.4	13.2	7.7	14.6	9.8	12.7	18.6	100.0

Taulukko 21. Keskikuutio kuorellista puuta kasvullisen metsämaan hehtaaria kohti vuosina 1951—53 ja metsämaan hehtaaria kohti vuosina 1964—70.

Table 21. Mean volume, including bark, on productive forest land in 1951—53 and on forest land in 1964—70.

Piirimetsälautakunta *Forestry Board District*	1951—53	1964—70	Piirimetsälautakunta *Forestry Board District*	1951—53	1964—70
	m³/ha			m³/ha	
0. Ahvenanmaa	87	115	10. Pohjois-Karjala	93	85
1. Helsinki	95	111	11. Pohjois-Savo	91	84
2. Lounais-Suomi	94	98	12. Keski-Suomi	99	81
3. Satakunta	90	82	13. Etelä-Pohjanmaa	68	74
4. Uusimaa-Häme	109	109	14. Vaasa	84	91
5. Pirkka-Häme	101	98	15. Keski-Pohjanmaa	63	68
6. Itä-Häme	112	104	16. Kainuu	86	70
7. Etelä-Savo	103	106	17. Pohjois-Pohjanmaa	56	51
8. Etelä-Karjala	99	97	18. Koillis-Suomi	63	51
9. Itä-Savo	105	101	19. Lappi	55	49
Eteläpuolisko — *Southern half*	94	90	Pohjoispuolisko — *Northern half*	63	54
Koko maa — *Whole country*	81	75			

Keskikuutiot piirimetsälautakuntien alueittain metsämaan hehtaaria kohti on esitetty taulukossa 21 ja kuvassa 10 (vert. myös Taulukko 24 ja Liitetaulukko 16). Verrattaessa keskikuutioita 1950-luvun alun tilanteeseen on otettava huomioon, että aikaisempaan kasvulliseen metsämaahan verrattuna metsä- ja kitumaan rajan muuttumisen vuoksi Ahvenanmaalla metsämaa on pienentynyt ja muualla eteläpuoliskossa suurentunut sekä Perä-Pohjolassa säilynyt likimain ennallaan. Keskikuutioiden suureneminen tai säilyminen ennallaan III ja V inventoinnin välisenä aikana merkitsee yleensä hakkuusäästöjen kertymistä kestävään suunnitteeseen verrattuna. Etelä- ja Keski-Pohjanmaalla on tapahtunut aikaisemman vajaapuustoisuuden korjaantumista. Keskikuution selvä pieneneminen ennen muuta maan itä- ja pohjoisosissa osoittaa vastaavasti ylihakkuun tapahtumista.

Maan eteläpuoliskossa keskikuution pieneneminen 94 m³:stä 90 m³:iin johtuu yksin omaan metsämaan suurenemisesta aikaisempaan kasvulliseen metsämaahan verrattuna siten, että siihen on tullut pienikuutioisia aikaisemman huonokasvuisen metsämaan parhaita osia ja ojitustoiminnalla metsämaaksi muutettuja inventoinnin ajankohtana pienipuustoisia alueita. Pohjoispuoliskossa keskikuution selvä pieneneminen johtuu kutakuinkin kokonaan kuutiomäärän pienenemisestä.

Nykymetsien keskikuution (Taulukko 18) vertaaminen täysitiheän talousmetsän keskikuutioon on vaikeata ennen muuta siksi, että suuralueelle ei ole valmistettu riittävän yksityiskohtaisia, realistisesti saavutettavissa olevia tavoitepuustosarjoja. Kasvu- ja tuotostaulukoiden sarjat ovat »koealaolosuhteista» ja niiden keskikuutiot ovat liian suuria kuvaamaan sellaisenaan tavoitepuuston keskikuutiota. Suuruusluokkaa osoittavana havaintona voi-

taneen esittää, että kehitysluokkien 4, 5 ja 6, so. harvennus- ja väljennys- sekä uudistuskypsien metsiköiden keskikuutio on noin 15 % liian pieni. Keskikuution alhaisuus johtuu vajaatuottoisten pienikuutioisten metsiköiden suhteellisesta runsaudesta ja liian voimakkaista kasvatushakkuista. Toisaalta voimakkaat kasvatushakkuut ovat 1950- ja 60-luvulla olleet luonteeltaan alaharvennuksia, joten nykyinen korjuukypsä ja sitä lähestyvä

Taulukko 22. Puuston kuorellinen kuutiomäärä puulajeittain ja omistajittain maan etelä- ja pohjoispuoliskossa 1964—70.

Table 22. Growing stock volume, including bark, by tree species and ownership categories in Southern and Northern half of the country in 1964—70.

Puulaji *Tree species*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*
	% kuutiomäärästä — % *of volume*					Milj. m³ Mill. m³ / %
	Eteläpuolisko — *Southern half*					
Mänty — *Pine*	37.4	46.7	51.8	45.1	40.5	390
Kuusi — *Spruce*	42.3	39.7	34.7	40.7	41.8	414
Lehtip. — *Dec. spp.*	20.3	13.6	13.5	14.2	17.7	191
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	995
	Pohjoispuolisko — *Northern half*					
Mänty — *Pine*	50.2	56.8	56.9	72.2	63.5	246
Kuusi — *Spruce*	29.8	29.8	25.8	18.3	23.5	125
Lehtip. — *Dec. spp.*	20.0	13.4	17.3	9.5	13.0	82
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	453
	Koko maa — *Whole country*					
Mänty — *Pine*	39.8	48.0	55.9	49.2	56.6	636
Kuusi — *Spruce*	39.9	38.4	27.5	37.3	29.0	539
Lehtip. — *Dec. spp.*	20.3	13.6	16.6	13.5	14.4	273
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	1 448
	Eteläpuolisko — *Southern half*					
Mänty — *Pine*	80.0	9.1	7.3	2.8	0.8	100.0
Kuusi — *Spruce*	85.0	7.2	4.6	2.4	0.8	100.0
Lehtip. — *Dec. spp.*	88.3	5.3	3.9	1.8	0.7	100.0
Yhteensä — *Total*	83.7	7.6	5.5	2.4	0.8	100.0
	Pohjoispuolisko — *Northern half*					
Mänty — *Pine*	39.5	2.6	52.1	1.3	4.5	100.0
Kuusi — *Spruce*	46.3	2.7	47.1	0.6	3.3	100.0
Lehtip. — *Dec. spp.*	47.2	1.8	47.7	0.5	2.8	100.0
Yhteensä — *Total*	42.7	2.5	49.9	1.0	3.9	100.0
	Koko maa — *Whole country*					
Mänty — *Pine*	64.3	6.6	24.7	2.2	2.2	100.0
Kuusi — *Spruce*	76.0	6.2	14.5	2.0	1.3	100.0
Lehtip. — *Dec. spp.*	75.9	4.3	17.1	1.4	1.3	100.0
Yhteensä — *Total*	70.8	6.0	19.5	2.0	1.7	100.0

Taulukko 23. Puuston kuutiomäärän jakaantuminen omistajittain 1920- ja 1960-luvuilla.

Table 23. Growing stock volume by ownership categories in decades of 1920—1960.

Ajankohta *Time*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*	Kuutiomäärä *Volume*
	% kuutiomäärästä — % *of volume*						Milj. m³ Mill. m³
	Eteläpuolisko — *Southern half*						
1951—53	77.9	11.5	7.2	3.4		100.0	980
1964—68	83.7	7.6	5.5	2.4	0.8	100.0	995
	Pohjoispuolisko — *Northern half*						
1951—53	35.1	3.7	60.4	0.8		100.0	513
1969—70	42.7	2.5	49.9	1.0	3.9	100.0	453
	Koko maa — *Whole country*						
1920—24	50.4	9.7	37.5	2.4		100.0	1 588
1936—38	53.6	10.0	33.1	3.3		100.0	1 560
1951—53	63.2	8.9	25.5	2.4		100.0	1 493
1964—70	70.8	6.0	19.5	2.0	1.7	100.0	1 448

puusto on harvahkoa ja järeätä, ts. koneellistuvan korjuun kustannusten kannalta erittäin edullista.

Puuston kuutiomäärän jakaantumista omistajien kesken kuvaavat tulokset on esitetty taulukoissa 22 ja 23. Erityisen silmiinpistävä on yksityismetsien kuutiomääräosuuden voimakas suureneminen, joka on ollut suhteellisesti paljon selvempää kuin metsämaan osuuden kasvu (vert. s. 16). Yksityisomistuksen metsämaan osuus on suurentunut 1920-luvun alusta 19 % ja kuutiomäärän osuus 40 %. Vastaavanlainen pieneneminen on tapahtunut valtion omistuksessa. Yhtiöillä on metsämaan osuus pienentynyt 7 % ja kuutiomäärän osuus niinkin paljon kuin 38 %. Esim. valtion metsien puuston kuutiomäärän suhteellinen pieneneminen vastaa nykyistä koko maan puustoa vertauskohtana pitäen 261 milj. m³.

Omistajittainen keskikuutioiden tarkastelu ottamalla kasvuolosuhteiden erot huomioon osoittaa, että kehitysluokkien 4, 5 ja 6 vajaakuutioisuus on suurempi yksityismetsissä kuin valtion ja yhtiöiden metsissä. Kokonaispuuston suuri keskikuutio yksityismetsissä johtuu kasvuolosuhteiden eroista ja vähäisemmästä päätehakkuutoiminnasta verrattuna valtion ja yhtiöiden metsiin.

Yksityismetsien metsämaan ja puuston kuutiomääräosuuksien kehittymiseen suhteessa muihin omistajaryhmiin on kaksi syytä. Ensinnäkin uusien tilojen muodostamisessa valtion ja yhtiöiden maista on siirron kohteena ollut suhteellisesti eniten puustoa sisältävät alueet. Tämä on ollut tärkein tekijä pohjoispuoliskossa maata, jossa päätehakkuu ja uudistustoiminta on

Taulukko 24. Keskikuutio kuorellista puuta metsämaalla kehitysluokittain ja omistajittain maan etelä- ja pohjoispuoliskossa 1964—70.

Table 24. Mean volume, including bark, by development classes on forest land by ownership categories in Southern and Northern half of the country in 1964—70.

Omistaja *Owner*	Kehitysluokka — *Development class*									Yhteensä *Total*
	1	2	3	4	5	6	7	8	9	
	m³/ha									
	Eteläpuolisko — *Southern half*									
Yksityinen — *Private*	9	63	13	99	150	154	87	78	—	94
Osakeyhtiö — *Company*	9	51	7	87	139	152	80	63	—	67
Valtio — *State*	5	37	7	80	145	172	83	112	176	76
Kunta, seurakunta — *Commune, church*	11	57	8	92	142	151	89	74	138	86
Yhteisö — *Corporation*	7	64	9	82	131	144	94	74	109	79
Yhteensä — *Total*	9	60	11	97	148	155	86	79	171	90
	Pohjoispuolisko — *Northern half*									
Yksityinen — *Private*	8	33	10	60	99	101	48	50	—	53
Osakeyhtiö — *Company*	9	14	5	56	107	118	57	40	—	40
Valtio — *State*	8	32	8	57	94	97	40	67	131	55
Kunta, seurakunta — *Commune, church*	9	40	8	64	106	95	39	18	—	47
Yhteisö — *Corporation*	13	43	9	70	96	96	41	70	—	70
Yhteensä — *Total*	8	32	9	59	97	98	44	59	131	54
	Koko maa — *Whole country*									
Yksityinen — *Private*	9	53	12	90	140	137	80	69	—	82
Osakeyhtiö — *Company*	9	42	7	82	134	145	78	57	—	62
Valtio — *State*	8	32	8	62	102	106	49	71	150	58
Kunta, seurakunta — *Commune, church*	10	54	8	85	134	139	80	65	138	76
Yhteisö — *Corporation*	10	50	9	74	108	103	70	71	109	73
Yhteensä — *Total*	9	46	10	85	133	126	74	69	149	75

1 = Aukea uudistusala tai siemenpuusto — *Open area or seed tree stand*
2 = Taimisto tai riukuvaihe sekä ylispuita — *Seedling or sapling stand with standards*
3 = Taimisto tai riukuvaihe — *Seedling or sapling stand*
4 = Harvennusmetsikkö — *Thinning stand*
5 = Väljennysmetsikkö — *Accretion stand*
6 = Uudistuskypsä metsikkö — *Mature stand*
7 = Suojuspuumetsikkö — *Shelterwood stand*
8 = Vajaatuottoinen metsikkö — *Low-yielding stand*
9 = Luonnonsuojelualue — *Nature conservation area*

yksityismetsissä ollut vähintään yhtä voimakasta kuin valtion metsissä (vert. Taulukko 17). Ts. maan pohjoispuoliskossa yksityismetsien tähänastinen päätehakkuu- ja uudistustoiminta olisi ollut ilman uusien tilojen muodostamisessa saatuja suurikuutioisia päätehakkuuikäisiä metsiköitä kestävyyden ylittävää. Vastaavasti valtion metsien päätehakkuutoiminta ei olisi ollut kestävyyttä ylittävää ellei samanaikaisesti olisi korjuukypsää puustoa siirretty yksityisomistukseen.

Maan eteläpuoliskossa uusien tilojen muodostamisen johdosta tapahtunut suurikuutioisten metsiköiden saaminen yksityisomistukseen on ollut myös kehitykseen vaikuttava tekijä, mutta tärkein syy kuutiomääräosuuden voimakkaaseen suurenemiseen on ollut kestäviä hakkuumahdollisuuksia pienempi päätehakkuu- ja uudistustoiminta (vert. Taulukko 17).

Riippumatta siitä onko omistajaryhmittäistä kestävyyttä pidettävä suotavana tavoitteena vai ei, voidaan todeta, että yhtiöiden metsissä niiden kuutiomääräosuuden pieneneminen on johtunut pääosaksi kestävyyden ylittäneestä päätehakkuu- ja uudistustoiminnasta. Valtion metsissä taas kuutiomääräosuuden ja siitä riippuvien hakkuumahdollisuuksien voimakas pieneneminen on johtunut pääasiassa hakkuukypsän puuston siirtämisestä yksityisomistukseen uusia tiloja muodostettaessa. Kuitenkin voidaan huomauttaa, että jos valtion metsissä kestävyys olisi ollut ehdoton tavoite, niin metsäomaisuuden siirto olisi pitänyt ottaa huomioon toteutettaessa valtion metsien käsittelyä.

Harkittaessa kestävään metsätalouteen liittyvää tilannetta koko maan puitteissa ja pitämällä yhteiskunnan puun tarpeen tyydyttämistä ensisijaisena tavoitteena, niin hakkuutoiminnan erilainen painottaminen eri omistajien metsissä ja siitä seurauksena tapahtunut kuutiomäärän osuuksien kehittyminen ovat olleet kokonaisuuden kannalta järkevää, koska päätehakkuut ovat kohdistuneet puuston vanhimpiin ja hidaskasvuisimpiin osiin ja hakkuusäästöt ovat olleet hakattua puustoa paremmin kasvavia. Itse asiassa tämä periaate sisältyy valtakunnan metsien III inventoinnin tulosjulkaisuissa esitettyihin metsän käsittelyn suosituksiin. Toisaalta alueittaisista kestävyyden ylittäneistä hakkuista on taas seurauksena työvoiman sijoitusvaikeuksia ja vaikeuksia voi myös seurata siitä, että teollisuuden puun hankintaa joudutaan suuntaamaan alueellisesti toisella tavalla kuin aikaisemmin. Niinpä alueilla, joissa on paljon valtion ja yhtiöiden metsiä, metsätyön tarjonta pienenee ja aiheuttaa työttömyyttä. Samoin näiden alueiden puun tarjontaa hyväksi käyttänyt teollisuus joutuu mukautumisvaikeuksiin siirtäessään hankintojaan »muiden tehtaiden alueille». Teollisuuden puun saannin suureneva riippuvuus yksityismetsistä voi myös lisätä raakapuun saannin vaikeuksia, jos valtakunnallisen tulonjaon erimielisyystilanteissa puun tarjonta yksityismetsistä pienenee.

Puuston läpimittaluokkarakenne

Puuston runkoluvun jakaantuminen läpimittaluokkiin vuosina 1964—70 on esitetty taulukossa 25 ja kuutiomäärän jakaantuminen taulukossa 26. Jälkimmäisessä taulukossa on myös aikaisempien inventointien tulokset. Kehitystä havainnollistavat kuvat 12 ja 13.

Taulukko 25. Runkoluvun jakaantuminen 1 cm:n rinnankorkeusläpimittaluokkien ryhmiin metsämaalla 1964—70.

Table 25. Distribution of stems by groups of 1 cm BDH-classes on forest land in 1964—70.

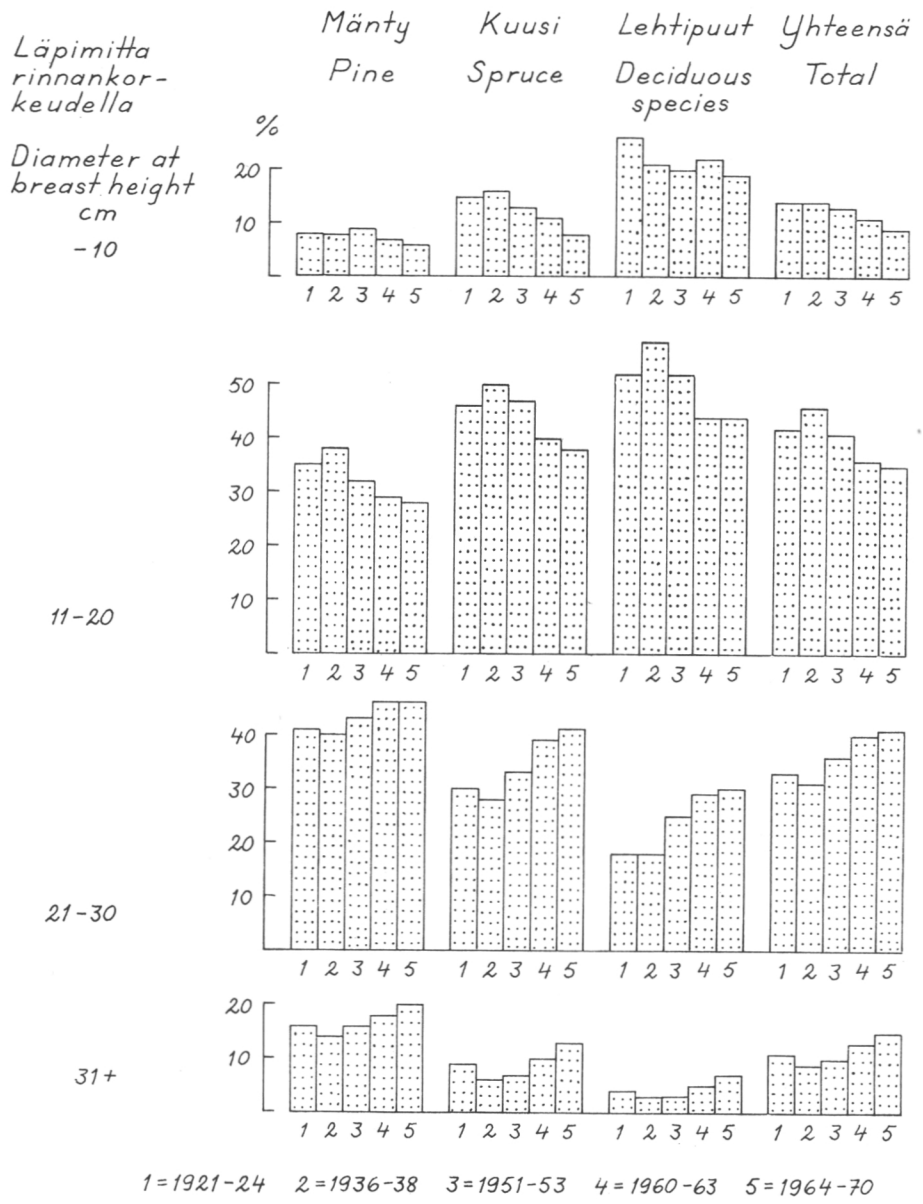
Puulaji *Tree species*	1 cm:n rinnankorkeusläpimittaluokkien ryhmät *Groups of 1 cm DBH-classes*									Yhteensä *Total*
	3—4	5—9	10—14	15—19	20—24	25—29	30—34	35—39	40+	
	% runkoluvusta -- % *of stem number*									
	Eteläpuolisko — *Southern half*									
Mänty — *Pine*	22.6	32.2	17.5	11.7	8.7	5.0	1.8	0.4	0.1	100.0
Kuusi — *Spruce*	25.2	37.5	18.0	10.0	5.7	2.5	0.8	0.2	0.1	100.0
Lehtip. — *Dec. spp.*	41.4	37.6	11.9	5.0	2.7	1.0	0.3	0.1	0.0	100.0
Yhteensä — *Total*	30.1	36.2	15.8	8.7	5.4	2.7	0.9	0.2	0.0	100.0
	Pohjoispuolisko — *Northern half*									
Mänty — *Pine*	29.4	35.9	15.1	8.5	5.6	3.2	1.4	0.6	0.3	100.0
Kuusi — *Spruce*	22.3	39.5	21.1	9.8	4.6	1.8	0.6	0.2	0.1	100.0
Lehtip. — *Dec. spp.*	38.1	40.3	14.8	4.9	1.4	0.4	0.1	0.0	0.0	100.0
Yhteensä — *Total*	30.7	38.4	16.5	7.6	3.8	1.8	0.8	0.3	0.1	100.0
	Koko maa — *Whole country*									
Mänty — *Pine*	25.7	33.9	16.4	10.2	7.3	4.2	1.6	0.5	0.2	100.0
Kuusi — *Spruce*	24.4	38.1	18.8	9.9	5.4	2.3	0.8	0.2	0.1	100.0
Lehtip. — *Dec. spp.*	40.1	38.6	13.0	5.0	2.2	0.8	0.2	0.1	0.0	100.0
Yhteensä — *Total*	30.3	37.0	16.1	8.3	4.9	2.3	0.8	0.2	0.1	100.0

Puuston järeyssuhteiden kehityksen mielenkiintoisimpia piirteitä on, että suurimpien puiden osuus kuutiomäärästä pieneni 1920- ja 1930-luvulla ja on sen jälkeen suurentunut, varsinkin 1950- ja 1960-luvulla. Syynä suurimpien puiden kuutiomääräosuuden pienenemiseen itsenäisyyden alussa oli todennäköisesti suurentunut puun korjuu, joka silloisissa menekkioloissa oli useimmiten järeiden puiden harsintaa. Sahaus oli suhteellisesti paljon tärkeämpi jalostuksen muoto kuin myöhemmin. Laajoilla alueilla polttopuu oli ainoa säännöllisesti kysytty pinotavara. Uusien taimistojen kautta tapahtuva metsän uudistaminen oli harvinaista ja puusto nuortui alikasvosten ja metsiköiden nuoremman osan vapautuessa, kuten ikärakenteen kehittyminen osoittaa (Kuva 5).

Ikärakenteen kehitys viittaa myös siihen, että 1920- ja 1930-luvulla korjuu painottui vanhimpiin ja järeimpiin metsikköihin lukuun ottamatta maan kaikkein pohjoisimpia osia, jotka olivat säännöllisen korjuun ulkopuolella. Metsien pinta-alasta oli suhteellisesti suurin osa 21—80 vuotisten metsiköiden hallussa eikä näistä varsinkaan nuorimmissa ollut vielä paljon silloisen teollisuuden raakapuun mitat täyttäviä runkoja. II inventoinnin tulosten mukainen kuutiomäärän arvio oli myös pienempi kuin I inventoinnin arvio. Tilastollisesti ero ei ole tosin merkitsevä, mutta järeän puuston osuuden pienenemisen kanssa se muodostaa johdonmukaisen kokonaisuuden.

Taulukko 26. Puuston kuutiomäärä läpimittaluokittain ja sen kehittyminen.
Table 26. Volume of the growing stock by diameter classes and its development.

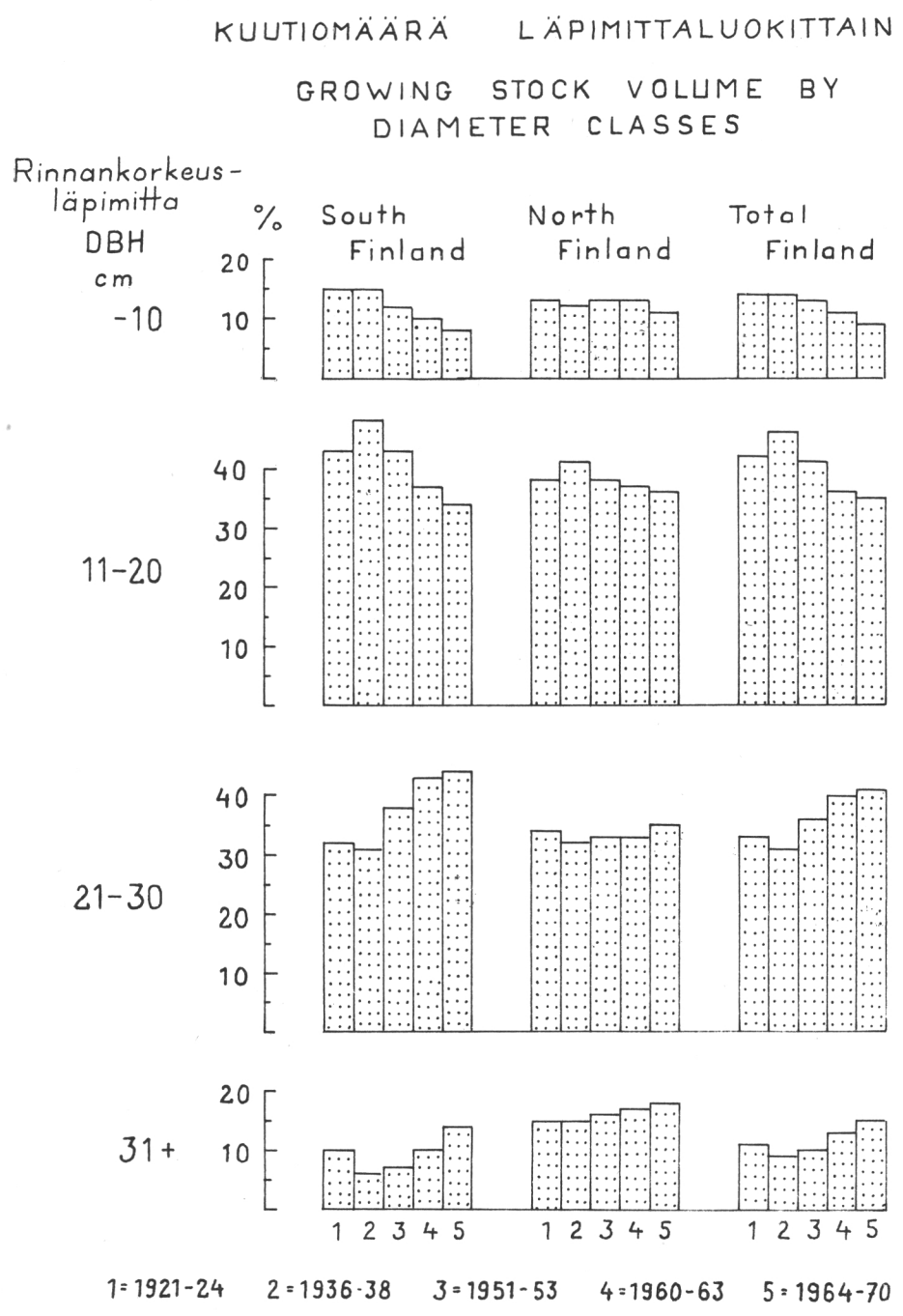
Aika *Time*	Mänty — *Pine*					Kuusi — *Spruce*					Lehtipuut — *Decid.spp.*					Yhteensä — *Total*				
	Rinnankorkeusläpimitta, cm — *Diameter at breast height, cm*																			
	—10	11—20	21—30	31+	Yht. *Total*	—10	11—20	21—30	31+	Yht. *Total*	—10	11—20	21—30	31+	Yht. *Total*	—10	11—20	21—30	31+	Yht. *Total*
	% kuutiomäärästä — % *of volume*																			
	Eteläpuolisko — *Southern half*																			
1921—24	9	38	40	13	100	16	48	30	6	100	22	52	20	6	100	15	43	32	10	100
1936—38	9	43	39	9	100	17	52	27	4	100	18	58	20	4	100	15	48	31	6	100
1951—53	8	36	46	10	100	13	47	34	6	100	16	51	29	4	100	12	43	38	7	100
1960—63	7	30	49	14	100	10	39	41	10	100	18	42	34	6	100	10	37	43	10	100
1964—68	5	28	50	17	100	8	36	43	13	100	17	40	35	8	100	8	34	44	14	100
	Pohjoispuolisko — *Northern half*																			
1921—24	7	30	42	21	100	14	42	31	13	100	31	53	14	2	100	13	38	34	15	100
1936—38	6	32	40	22	100	13	45	30	12	100	28	58	12	2	100	12	41	32	15	100
1951—53	8	28	39	25	100	13	45	32	10	100	29	53	16	2	100	13	38	33	16	100
1960—63	8	28	40	24	100	12	44	32	12	100	30	49	17	4	100	13	37	33	17	100
1969—70	8	27	40	25	100	10	43	35	12	100	25	53	18	4	100	11	36	35	18	100
	Koko maa — *Whole country*																			
1921—24	8	35	41	16	100	15	46	30	9	100	26	52	18	4	100	14	42	33	11	100
1936—38	8	38	40	14	100	16	50	28	6	100	21	58	18	3	100	14	46	31	9	100
1951—53	9	32	43	16	100	13	47	33	7	100	20	52	25	3	100	13	41	36	10	100
1960—63	7	29	46	18	100	11	40	39	10	100	22	44	29	5	100	11	36	40	13	100
1964—70	6	28	46	20	100	8	38	41	13	100	19	44	30	7	100	9	35	41	15	100



Kuva 12. Puuston puulajeittaisen kuutiomäärän läpimittaluokkiin jakaantumisen kehittyminen 1920—70.

Fig. 12. Development of the growing stock volume by tree species and diameter classes 1920—70.

Edellä todettu järeyssuhteiden kehittyminen 1920- ja 1930-luvulla oli selvin maan eteläpuoliskossa, jossa menekkiolot olivat paremmat kuin pohjoispuoliskossa. Kehitys oli samanlainen kaikilla puulajeilla, ei kuitenkaan



Kuva 13. Puuston kuutiomäärän läpimittaluokkiin jakaantumisen kehittyminen maan etelä- ja pohjoispuoliskossa 1920—70.

Fig. 13. Development of the growing stock volume by diameter classes in Southern and Northern half of the country 1920—70.

yhtä selvä lehtipuilla kuin havupuilla. Ero johtunee koivun silloisesta heikommasta menekistä havupuihin verrattuna.

1940-luvulla todettavissa oleva järeän puuston suhteellisen osuuden voimakas lisääntyminen johtui sodan vuoksi vähäisestä korjuusta ja ikärakenteesta, joka alkoi kasata päätehakkuuikää lähestyviä metsiköitä. Jälleen kehitys oli selvempi eteläpuoliskossa kuin pohjoispuoliskossa, joka selittyy sillä, että pohjoispuoliskon vanhoissa ja muutenkin hitaammin kasvavissa metsiköissä siirtymä oli paljon hitaampaa kuin etelässä.

Puuston suhteellinen järeytyminen on ollut 1950- ja 1960-luvulla vielä nopeampaa kuin 1940-luvulla. Jos pidetään puuston kuutiomäärää muuttumattomana, niin yli 20 cm rinnankorkeusläpimitaltaan olevien puiden kuutiomäärä on muuttunut inventointien välissä seuraavan asetelman mukaan:

Vuosi	1922 —37	—52	—61	—67
Muutos vuotta kohti, %	—0.6	+0.9	+1.7	+1.2

Järeytyminen on ollut suhteellisesti voimakkainta 1950-luvulla, jolloin selluloosateollisuus laajeni voimakkaasti, paperipuun vienti oli suurta ja jolloin alaharvennus yleistyi metsien käsittelyssä.

Vaikka puuston järeytymisen luontainen syy onkin ikärakenteessa ja sen kehittymisessä, on toisaalta otettava huomioon, että samana aikana korjatut puumäärät ovat olleet erittäin suuret ja että pinotavaran kantohinta on ollut tukin kantohintaan verrattuna männyllä noin 40 % ja kuusella noin 60 %. Kantohinta- ja metsän omistusolosuhteissa puuston järeyden lisääntyminen on voitu saada aikaan vain yksityismetsälain valvonnalla ja siihen liittyvällä metsätalouden edistämisellä. Metsien käsittelyssä tapahtui 1950- ja 1960-luvulla kaksi merkittävää muutosta aiempiin aikoihin verrattuna. Alaharvennusten luontoiset kasvatushakkuut ja selvät uusiin taimistoihin johtavat päätehakkuut yleistyivät. Ilman näitä kahta muutosta metsävarat eivät olisi tuotannon jatkuvuutta ja korjuun taloudellisuutta ajatellen selviytyneet yhtä hyvin yhteiskunnan puun tarvetta tyydyttäneistä raskaista hakkuista.

Rinnankorkeusläpimitaltaan vähintään 20 cm olevien puiden osuus kuutiomäärästä on seuraavan asetelman mukainen

	mänty	kuusi	lehtipuut	yhteensä
	% kuutiomäärästä			
eteläpuolisko	67	56	43	58
pohjoispuolisko	65	47	22	53
koko maa	66	54	37	56

Taulukko 27. Tukkirunkojen (rinnankorkeusläpimitta vähintään 19.5 cm) lukumäärä metsämaalla 1964—70.

Table 27. Number of saw timber stems (DBH at least 19.5 cm) on forest land in 1964—70.

Puulaji *Tree species*	1 cm rinnankorkeusläpimittaluokkien ryhmät *Groups of 1 cm DBH-classes*			
	20—24	25—29	30+	Yhteensä *Total*
	Milj. runkoa — *Mill. stems*			
	Eteläpuolisko — *Southern half*			
Mänty — *Pine*	266	181	81	528
Kuusi — *Spruce*	274	142	60	476
Lehtipuut — *Dec. spp.*	44	27	10	81
Yhteensä — *Total*	584	350	151	1 085
	Pohjoispuolisko — *Northern half*			
Mänty — *Pine*	130	91	61	282
Kuusi — *Spruce*	59	33	18	110
Lehtipuut — *Dec. spp.*	3	1	1	5
Yhteensä — *Total*	192	125	80	397
	Koko maa — *Whole country*			
Mänty — *Pine*	396	272	142	810
Kuusi — *Spruce*	333	175	78	586
Lehtipuut — *Dec. spp.*	47	28	11	86
Yhteensä — *Total*	776	475	231	1 482

Taulukko 28. Tukkirunkojen (rinnankorkeusläpimitta vähintään 19.5 cm) kuorellisen kuutiomäärän jakaantuminen 1 cm:n rinnankorkeusläpimittaluokkien ryhmiin metsämaalla 1964—70.

Table 28. Volume, incl. bark, of saw timber stems (DBH at least 19.5 cm) by groups of 1 cm DBH-classes 1964—70.

Puulaji *Tree species*	1 cm rinnankorkeusläpimittaluokkien ryhmät *Groups of 1 cm DBH-classes*					Yhteensä *Total*	
	20—24	25—29	30—34	35—39	40+		
	% kuutiosta — % *of volume*						Milj. m^3 *Mill.* m^3
	Eteläpuolisko — *Southern half*						
Mänty — Pine	34.8	37.8	19.6	6.1	1.7	100.0	238
Kuusi — *Spruce*	41.0	34.8	16.9	5.4	1.9	100.0	214
Lehtip. — *Dec. spp.*	40.6	38.0	16.1	4.1	1.2	100.0	37
Yhteensä — *Total*	37.9	36.5	18.2	5.7	1.7	100.0	489
	Pohjoispuolisko — *Northern half*						
Mänty — *Pine*	29.5	32.8	21.0	10.7	6.0	100.0	123
Kuusi — *Spruce*	37.6	32.9	17.8	7.5	4.2	100.0	42
Lehtip. — *Dec. spp.*	45.9	36.5	13.5	2.3	1.8	100.0	2
Yhteensä — *Total*	31.7	32.9	20.1	9.8	5.5	100.0	167
	Koko maa — *Whole country*						
Mänty — *Pine*	32.9	36.1	20.1	7.7	3.2	100.0	361
Kuusi — *Spruce*	40.5	34.5	17.0	5.7	2.3	100.0	256
Lehtip. — *Dec. spp.*	40.8	38.0	16.0	4.0	1.2	100.0	39
Yhteensä — *Total*	36.3	35.6	18.7	6.7	2.7	100.0	656

Kun otetaan huomioon siirtymä ja korjuussa päätehakkuiden suhteellisen osuuden lisääntyminen, voidaan sanoa, että 1970-luvulla korjattavissa olevasta puumäärästä on männyn osalla 70 %, kuusen 60 ja lehtipuun 45 % vähintään 20 cm rinnankorkeusläpimitaltaan olevia runkoja. Ajateltaessa korjuun kustannusten kehittymistä siten, että pienet rungot muuttuvat korjuun koneellistumisen nykyisessä vaiheessa yhä epäedullisemmiksi suuriin runkoihin verrattuna, metsien nykyinen järeys- ja ikärakenne ovat arvaamattoman suuri etu. Nousevien työpalkkojen ja korjuukustannusten kierteessä tämä etu todennäköisesti ylittää paljon puhutusta metsien alhaisesta tiheydestä aiheutuvan kuutiotuotoksen menetyksen, jota olisi voitu viimeaikaisen puun käytön puitteissa estää vain lisäämällä runkojen lukumäärää ja pienentämällä järeyttä.

Tukkipuusto

Tukkirunkojen lukumäärä läpimittaluokittain, tukkipuuston kuutiomäärän jakaantuminen läpimittaluokkiin ja tukkirunkojen lukumäärän kehittyminen 1936—1970 on esitetty taulukoissa 27, 28 ja 29.

Taulukko 29. Vähintään 20 cm rinnankorkeusläpimitaltaan olevien tukkipuurunkojen lukumäärä ja lukumäärä kasvullisen metsämaan hehtaaria kohti 1936—38 ja 1951—53 sekä metsämaan hehtaaria kohti 1964—70 (suluissa lukumäärä, kun pienin läpimitta on 19.5 cm).

Table 29. Number of saw timber stems, at least 20 cm of breast height diameter, and the number per hectare of productive forest land in 1936—38 and 1951—53 and of forest land in 1964—70 (in the brackets the number when the minimum diameter is 19.5 cm).

Aika *Time*	Mänty — *Pine*		Kuusi — *Spruce*		Lehtip. — *Dec.spp.*		Yhteensä — *Total*	
	Milj. kpl *Mill. stems*	Kpl/ha *Stems/ha*	Milj. kpl *Mill. stems*	Kpl/ha *Stems/ha*	Milj. kpl *Mill. stems*	Kpl/ha *Stems/ha*	Milj. kpl *Mill. stems*	Kpl/ha *Stems/ha*
	Eteläpuolisko — *Southern half*							
1936—38 [1]	456	38	241	20	66	5	763	63
1951—53	470	47	330	33	87	9	887	89
1964—68	509	47	452	41	79	7	1 040	95
1964—68	(528)	(48)	(476)	(44)	(81)	(7)	(1 085)	(99)
	Pohjoispuolisko — *Northern half*							
1936—38 [1]	287	38	111	15	7	1	405	54
1951—53	291	39	110	15	8	1	409	55
1969—70	272	35	105	14	5	1	382	49
1969—70	(282)	(36)	(110)	(14)	(5)	(1)	(397)	(51)
	Koko maa — *Whole country*							
1936—38 [1]	743	38	352	18	73	4	1 168	60
1951—53	761	44	440	25	95	5	1 296	75
1964—70	781	42	557	30	84	4	1 422	76
1964—70	(810)	(43)	(586)	(31)	(86)	(5)	(1 482)	(79)

[1] Pinta-ala ennen v. 1940 — *Area before 1940.*

Tukkipuuston kuutiomäärän läpimittaluokkiin jakaantumisen osalta voitaneen kiinnittää huomiota siihen, että maan pohjoispuoliskossa tukkipuusto on suhteellisesti järeämpää kuin eteläpuoliskossa huolimatta kasvupaikkojen viljavuuseroista. Syynä tähän on yli-ikäisten metsiköiden suhteellinen runsaus ja keski-ikäisten metsiköiden vähäisyys pohjoispuoliskossa. Tämä merkitsee myös sitä, että uusien tukkipuiden muodostuminen ja olemassa olevien järeyden lisääntyminen on ikärakenne-eron vuoksi pohjoispuoliskossa paljon vähäisempää kuin eteläpuoliskossa. Pohjoisessa tukkipuusto on suurelta osalta seisovaa ja osaksi lahoavaakin varastoa, kun taas etelässä se on lisääntyvää ja arvoaan lisäävää tuotannollista pääomaa.

Tukkipuiden lukumäärän kehittyminen osoittaa ikä- ja järeysrakenteen kehittymiseen liittyen selvää suurenemista 1930-luvulta lähtien. 1950-luvulla ja sen jälkeen tukkipuuston lisääntyminen on keskittynyt maan eteläpuoliskoon. Pohjoispuoliskossa sen sijaan tukkipuuston määrä on alkanut pienetä.

Mikäli puun käyttö ei lähitulevaisuudessa ylitä kestävää poistumaa, niin maan eteläpuoliskossa koivua lukuun ottamatta tukkipuiden määrän lisääntyminen jatkuu ainakin 1980-luvulle. Koivutukkipuusto ja pohjoispuoliskon tukkipuusto todennäköisesti pienenevät koko kuluvan vuosisadan loppuosan ajan.

KASVU, SUUNNITE JA PUUTASE

Kasvu

Puuston runkopuun kasvu on V inventoinnissa alun perin laskettu kuorellisena puuna. Koska aikaisempien inventointien tulokset, poistuma ja puutasetiedot on esitetty kuorettomana puuna, esitetään tässä yhteydessä myös V inventoinnin tuloksina saadut kasvun arviot pääasiassa kuorettomina. Kasvu kuorellisena puuna on kuitenkin taulukossa 33.

Valtakunnan metsien inventointien tulosten mukaiset vuotuisen kasvun arviot ja niiden jakaantuminen pääpuulajien kesken on esitetty taulukossa 30 ja arvioiden kehittyminen likimääräisesti tasoitettuna kuvassa 9. Arvioihin ei ole tehty korjauksia ilmaston vaihtelusta aiheutuvien muutosten poistamiseksi siitä syystä, että tähän tarkoitukseen ei näytä olevan riittävän luo-

Taulukko 30. Kasvun arviot (kuoretonta puuta vuotta kohti) ja pääpuulajien suhteellisten osuuksien kehittyminen.

Table 30. Increment estimates (excluding bark, per annum) and the proportions of the main tree species.

Puulaji *Tree species*	1921—24	1936—38	1951—53	1960—63	1964—70
	% kasvusta — *% of increment*				
	Eteläpuolisko — *Southern half*				
Mänty — *Pine*	46.2	40.3	35.9	32.6	32.2
Kuusi — *Spruce*	27.3	33.4	39.4	43.4	46.6
Lehtip. — *Dec. spp.*	26.5	26.3	24.7	24.0	21.2
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
Kasvu milj. m^3 — *Increment mill.* m^3	37.4	36.5	35.1	33.5	37.8
	Pohjoispuolisko — *Northern half*				
Mänty — *Pine*	43.1	47.1	48.6	52.2	52.1
Kuusi — *Spruce*	31.6	29.4	28.5	22.9	27.4
Lehtip. — *Dec. spp.*	25.3	23.5	22.9	24.9	20.5
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
Kasvu milj. m^3 — *Increment mill.* m^3	9.5	10.2	10.9	9.3	9.8
	Koko maa — *Whole country*				
Mänty — *Pine*	45.6	41.8	38.9	36.8	36.2
Kuusi — *Spruce*	28.2	32.5	36.8	39.0	42.7
Lehtip. — *Dec. spp.*	26.2	25.7	24.3	24.2	21.1
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
Kasvu milj. m^3 — *Increment mill.* m^3	46.9	46.7	46.0	42.8	47.6

tettavia tuloksia antavaa menetelmää (K u u s e l a 1964). Mm. IV inventoinnin tulosjulkaisuissa (I l v e s s a l o 1962, 1963; T i i h o n e n 1966, 1968) on tarkasteltu kasvun vaihtelua vuosilustoindeksien perusteella ja päätelty, että tämän inventoinnin muita selvästi pienempi arvio on aiheutunut kasvunmittausjakson keskimääräistä kylmemmästä ilmastosta. Toisaalta IV inventoinnin tuloksissa myös kuutiomäärän arvio oli muiden inventointien tulosten mukaisia arvioita pienempi.

Metsien kasvun arvio, kun otetaan huomioon aluemenetysten vaikutus, on ollut koko tarkastelujakson ajan suureneva. Viimeisin arvio 47.6 milj. m^3 on suurempi kuin kasvun arviot 46.9 ja 46.7 milj. m^3 ennen aluemenetyksiä.

Arvioiden suureneminen on kuitenkin johtunut pääosaksi kasvun arvioimismenetelmän muutoksista. III inventoinnissa kasvun arvio perustui 5 vuoden mittausjaksoon rinnankorkeusläpimitan osalta, kun edellisissä inventoinneissa mittausjakso oli 10 vuotta. V inventoinnissa on taas pyritty ottamaan huomioon 5 vuoden mittausjakson aikana metsästä korjattujen puiden kasvu, joka on ollut viimeaikaisen suuren poistuman vuoksi suhteellisesti suurempi kuin kolmen ensimmäisen inventoinnin aikana.

Arvioimismenetelmän muutosten vaikutuksesta voi esittää vain summittaisen arvion. Mittausmenetelmien teoreettisen tarkastelun (K u u s e l a 1953, 1964) ja mittaustulosten perusteella on pääteltävissä, että jos V inventoinnissa olisi käytetty II inventoinnin menetelmää, niin kasvun arvioksi olisi saatu enintään 44 milj. m^3. Joka tapauksessa näyttää varmalta, että kasvu on ollut suurimmillaan samanaikaisesti kuin puustokin, so. 1950-luvun alussa, jolloin metsien ikärakenne oli suuren kasvun kannalta edullinen ja jolloin kaikki sodan aikaiset hakkuusäästöt olivat metsässä.

Puuston vanhenemisen, järeyden lisääntymisen ja kuutiomäärän pienenemisen vuoksi kasvun olisikin pitänyt pienetä 1950-luvun alun jälkeen. Erityisesti on otettava huomioon, että tänä aikana on perustettu runsaasti uusia taimistoja, joista valtaosa on V inventoinnin aikana ollut niin pieniä, että niiden kasvu on ollut hyvin pieni eikä sekään ole ollut kaikki mitattavissa.

Maan eteläpuoliskon osalta sen sijaan näyttää varmalta, että kasvu on alkanut suureta. Ikä- ja järeysrakenteen kehityksen perusteella tapahtuvan kasvun suurenemisen ei olisi vielä pitänyt alkaa, mutta tämän korvaavat suoritetut metsänparannustyöt, ennen muuta ojitukset.

Turvemaiden metsissä tehtyjen erillistutkimusten perusteella on päätelty, että ilman ojitusta koko maan metsien kasvu olisi noin 4 milj. m^3 nykyistä pienempi (H e i k u r a i n e n 1971). Edellä on todettu, että nykyisellä metsätalouden maalla on suoritettu ojitusta noin 4.3 milj. ha:lla, joten ojituksella aikaan saatu lisäys olisi vajaat 1 m^3/ha. Kun otetaan huomioon, että ojitetusta turvemaasta oli V inventoinnin ajankohtana 59 % ojikkoa ja ojikoista osa kitumaata ja jonkin verran joutomaatakin, niin verrattaessa kasvun lisäystä metsien keskikasvuun (Taulukko 32) se tuntuu

Taulukko 31. Puuston kuoreton kuutiomäärä ja kasvu III ja V inventoinnin tulosten mukaan 1964—70.

Table 31. Volume of the growing stock and increment, both excluding bark, based on the results of III and V inventory in 1964—70.

Inventoinnin aika *Time of inventory*	Mänty *Pine*	Kuusi *Spruce*	Lehtipuu *Dec.spp.*	Yhteensä *Total*
	Milj. m³ ja % — *Mill. m³ and %*			
1951—53	Eteläpuolisko — *Southern half*			
Kuutio — *Volume*	329.3	319.5	175.6	824.4
Kasvu — *Increment*	12.60	13.80	8.70	35.10
Kasvu-% — *Incr. %*	3.8	4.3	5.0	4.3
1964—68				
Kuutio — *Volume*	327.3	349.9	160.1	837.3
Kasvu — *Increment*	12.17	17.63	8.03	37.83
Kasvu-% — *Incr. %*	3.7	5.0	5.0	4.5
1952—53	Pohjoispuolisko — *Northern half*			
Kuutio — *Volume*	218.5	129.7	79.0	427.2
Kasvu — *Increment*	5.30	3.10	2.50	10.90
Kasvu-% — *Incr. %*	2.4	2.4	3.2	2.6
1969—70				
Kuutio — *Volume*	206.0	104.5	66.9	377.4
Kasvu — *Increment*	5.09	2.68	2.00	9.77
Kasvu-% — *Incr. %*	2.5	2.6	3.0	2.6
1951—53	Koko maa — *Whole country*			
Kuutio — *Volume*	547.8	449.2	254.6	1 251.6
Kasvu — *Increment*	17.90	16.90	11.20	46.00
Kasvu-% — *Incr. %*	3.3	3.8	4.4	3.7
1964—70				
Kuutio — *Volume*	533.3	454.4	227.0	1 214.7
Kasvu — *Increment*	17.26	20.31	10.03	47.60
Kasvu-% — *Incr. %*	3.2	4.5	4.4	3.9

suurelta. Toisaalta on kuitenkin otettava huomioon, että Suomen soistumiselle alttiissa maastossa metsätalouden ja maatalouden ojituksilla aikaan saatu vaikutus ei rajoitu yksin omaan metsätalouden ojitettuihin turvemaihin. Epäedullinen vesitalous ilman ympäristössä suoritettua ojitusta olisi metsän kasvua muuallakin pienentävä. Ojitus on estänyt myös soistumisen kasvua pienentävää vaikutusta. Kaiken tämän perusteella edellä esitettyä 4 milj. m³:n suuruista ojituksella aikaansaatua kasvun lisäystä voitaneen pitää suuruusluokaltaan oikeana. Joka tapauksessa voidaan sanoa, että Suomen puutasetilanne olisi nykyistä paljon huonompi, jos metsäojituksia ei olisi tehty ollenkaan.

Kasvun kehittyminen tulevaisuudessa on riippuvainen ennen muuta uusien taimistojen ja ojitettujen turvemaiden metsiköiden kehittymisestä. Ellei korjuu olennaisesti pienennä puustoa, suurenee kasvu jo 1970-luvulla, mikä suureneminen nopeutuu 1980-luvulla. Mikäli metsien lannoitus li-

Taulukko 32. Keskikasvu kuoretonta puuta kasvullisen metsämaan hehtaaria kohti 1951—53 ja metsämaan hehtaaria kohti 1964—70.

Table 32. Mean increment, excluding bark, on productive forest land in 1951—53 and on forest land in 1964—70.

Piirimetsälautakunta *Forestry Board District*	1951—53	1964—70	Piirimetsälautakunta *Forestry Board District*	1951—53	1964—70
	m³/ha			m³/ha	
0. Ahvenanmaa	2.7	3.8	10. Pohjois-Karjala	3.0	2.9
1. Helsinki	3.6	3.7	11. Pohjois-Savo	3.3	3.4
2. Lounais-Suomi	3.5	3.6	12. Keski-Suomi	3.4	3.1
3. Satakunta	3.3	3.1	13. Etelä-Pohjanmaa	2.4	2.7
4. Uusimaa-Häme	4.3	4.3	14. Vaasa	2.9	2.9
5. Pirkka-Häme	3.6	3.8	15. Keski-Pohjanmaa	2.2	2.3
6. Itä-Häme	4.3	4.4	16. Kainuu	2.1	1.5
7. Etelä-Savo	4.0	4.3	17. Pohjois-Pohjanmaa	1.7	1.5
8. Etelä-Karjala	3.9	3.7	18. Koillis-Suomi	1.1	0.9
9. Itä-Savo	4.1	4.3	19. Lappi	1.0	1.0
Eteläpuolisko — *Southern half*	3.4	3.4	Pohjoispuolisko — *Northern half*	1.3	1.2
Koko maa — *Whole country*	2.5	2.5			

sääntyy suunnitelmien mukaisesti, alkaa kasvun voimakas suureneminen jo 1970-luvulla.

Puulajien kasvun osuuksien kehittymisen perusteella (Taulukot 30 ja 31 sekä kuva 9) voidaan todeta kuusesta tulleen kasvulla mitattuna pääpuulaji 1960-luvulla. Maan pohjoispuoliskossa kuusen osuus tosin on ilmeisestikin pienenevä, mutta eteläpuoliskossa sen osuus suurenee sitäkin selvemmin. Männyn osuus kasvusta on hitaasti pienenevä koko maassa ja eteläpuoliskossa, kun taas pohjoispuoliskossa se on suureneva. Männyn runsas uudistaminen pysähdyttänee sen kasvun osuuden pienenemisen jo lähitulevaisuudessa ellei korjuulla pienennetä mäntypuustoa tähänastista olennaisesti voimakkaammin. Lehtipuun kasvun osuus on aikaisemmin ollut verraten hitaasti pienenevä. Lehtipuuston iän ja 1960-luvulla saavutetun suuren poistuman vuoksi sen kasvussa on odotettavissa kiihtyvää pienenemistä. Kuten myöhemmin puutaseen yhteydessä todetaan, näyttää todennäköiseltä, että V inventoinnin kasvutulokset jonkin verran yliarvioivat kuusen kasvua ja aliarvioivat lehtipuun kasvua, mutta kasvun ja poistuman suhteiden perusteella on pääteltävissä, että tämä ei muuta edellä hahmoteltua kehitystä.

Kasvun suurena säilymistä on varsinkin maan eteläpuoliskossa edistänyt kuusen lisääntyminen, koska sillä on korkea kasvuprosentti mäntyyn verrattuna. Männyn alhainen kasvuprosentti johtuu vanhojen männiköiden runsaudesta ja männyn kasvamisesta muita puulajeja karummalla maalla, jossa kiertoaika on pitkä. Kuusen kasvuprosentin voimakas suureneminen III inventoinnin tuloksiin verrattuna johtunee siitä, että III ja V inventoinnin välillä vapautetut nopeakasvuiset kuusialikasvokset ovat saaneet entistä suuremman osan puustossa.

Taulukko 33. Puuston vuotuinen kasvu kuorellisena puuna puulajeittain ja omistajittain 1964—70.

Table 33. Annual increment, including bark, of the growing stock by tree species and ownership categories in 1964—70.

Puulaji *Tree species*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*
	% kasvusta — % *of increment*					Milj. m³ *Mill. m³* %
	Eteläpuolisko — *Southern half*					
Mänty — *Pine*	30.7	39.3	44.0	38.2	32.4	14.17
Kuusi — *Spruce*	47.0	45.5	40.4	46.1	47.0	20.51
Lehtip. — *Decid. spp.*	22.3	15.2	15.6	15.7	20.6	9.35
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	44.03
	Pohjoispuolisko — *Northern half*					
Mänty — *Pine*	48.9	55.2	54.3	72.7	62.2	5.95
Kuusi — *Spruce*	28.4	31.0	26.5	18.2	24.3	3.15
Lehtip. — *Decid. spp.*	22.7	13.8	19.2	9.1	13.5	2.36
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	11.46
	Koko maa — *Whole country*					
Mänty — *Pine*	33.2	40.6	50.9	41.6	47.9	20.12
Kuusi — *Spruce*	44.5	44.3	31.1	43.4	35.2	23.66
Lehtip. — *Deced. spp.*	22.3	15.1	18.0	15.0	16.9	11.71
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	55.49
	Eteläpuolisko — *Southern half*					
Mänty — *Pine*	80.5	9.0	7.0	2.7	0.8	100.0
Kuusi — *Spruce*	85.3	7.2	4.4	2.3	0.8	100.0
Lehtip. — *Decid. spp.*	88.6	5.2	3.8	1.7	0.7	100.0
Yhteensä — *Total*	84.5	7.3	5.1	2.3	0.8	100.0
	Pohjoispuolisko — *Northern half*					
Mänty — *Pine*	49.7	2.7	42.4	1.3	3.9	100.0
Kuusi — *Spruce*	54.6	2.9	39.0	0.6	2.9	100.0
Lehtip. — *Decid. spp.*	58.1	1.7	37.7	0.4	2.1	100.0
Yhteensä — *Total*	52.8	2.5	40.5	1.0	3.2	100.0
	Koko maa — *Whole country*					
Mänty — *Pine*	71.4	7.1	17.5	2.3	1.7	100.0
Kuusi — *Spruce*	81.2	6.6	9.0	2.1	1.1	100.0
Lehtip. — *Decid. spp.*	82.4	4.5	10.6	1.5	1.0	100.0
Yhteensä — *Total*	77.9	6.4	12.4	2.0	1.3	100.0

Keskikasvun arviot kasvullisen metsämaan ja metsämaan hehtaaria kohti piirimetsälautakuntien alueittain III ja V inventoinnin tulosten mukaan on esitetty taulukossa 32 ja kuvassa 10. Vertailuja suoritettaessa on otettava huomioon, että metsämaa on suurempi kuin kasvullinen metsämaa ja että kasvun arvioimismenetelmän muutos vaikuttaa tuloksiin, kuten edellä on kuvattu.

Taulukko 34. Puuston kasvun jakaantuminen omistajittain.
Table 34. Increment of the growing stock proportionally by ownership categories.

Aika *Time*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*
	%					
1921—24	65.3	10.8	21.3	2.6	—	100.0
1936—38	65.0	10.7	20.7	3.6	—	100.0
1951—53	72.2	8.9	16.3	2.6	—	100.0
1964—70	77.9	6.4	12.4	2.0	1.3	100.0

Kasvun jakautuminen metsänomistajien kesken V inventoinnin tulosten mukaan on esitetty taulukossa 33 ja kehitys vuosina 1920—70 taulukossa 34. Kasvusta ja siten myös lähiajan puun tuotantomahdollisuuksista on 77.9 % varsinaisissa yksityismetsissä. Osakeyhtiöiden metsien osuus on 6.4, valtion 12.4, kuntien ja seurakuntien 2.0 ja yhteisöjen, pääasiassa yhteismetsien 1.3 %.

Pitkäaikaiselle kehitykselle on ominaista, niin kuin metsämaan ja kuutiomäärän omistussuhteiden kehityksen perusteella on pääteltävissä, valtion ja yhtiöiden metsien kasvun osuuden voimakas pieneneminen ja yksityismetsien osuuden suureneminen. Jos pidetään nykytilannetta vertauskohtana, niin yksityismetsissä on kasvua 6 milj. m^3 enemmän kuin niissä olisi 1920-luvun alun omistussuhteiden mukaan. Yksityismetsien osuus kasvusta ei ole kuitenkaan suurentunut suhteellisesti yhtä paljon kuin osuus kuutiomäärästä, mikä johtuu siitä, että pääosa asutuksen ja uusien tilojen muodostamisen vuoksi siirtyneestä puustosta on vanhaa ja hidaskasvuista ja se sijaitsee myös epäedullisemmissa kasvuoloissa kuin aikaisempien yksityismetsien puusto. Valtion osuus kasvusta on pienentynyt lähes puoleen siitä, mitä se oli 50 vuotta sitten. Puun tuotantomahdollisuuksien väheneminen on vielä tätäkin suurempi, koska huomattava osa valtion metsistä sijaitsee kaikkein heikoimmissa kasvu- ja menekkioloissa.

Suunnite

Suunnite metsävarojen määrään ja rakenteeseen sekä puuston kasvuun ja toteutettavaan metsänparannustoimintaan perustuvana suurimpana kestävänä poistumana vuotta kohti on esitetty taulukossa 35 (vert. myös Kuvat 17 ja 18) V inventoinnin tulosten mukaan ja III inventoinnin tuloksiin perustuen sellaisena kuin se sisältyy metsätalouden suunnittelukomitean mietintöön (H e i k u r a i n e n ym. 1960). Jälkimmäisen suunnitteen kestävyyden perustana oli metsänparannustoiminta, jota 1950-luvun lopulla pidettiin tarpeellisena ja mahdollisena toteuttaa. Kuten kuvan 14 perusteella

Taulukko 35. III ja V inventoinnin arvioihin perustuvat kestävän suunnitteen arviot.
Table 35. Allowable drain on the basis of sustained yield estimated by 3. and 5. inventory.

Alue *Area*	1960				1970			
	Mänty *Pine*	Kuusi *Spruce*	Lehtip. *Dec.spp*	Yht. *Total*	Mänty *Pine*	Kuusi *Spruce*	Lehtip. *Dec.spp*	Yht. *Total*
	Milj. m³/vuosi, kuoretta — *Mill. m³/year, excluding bark*							
Eteläpuolisko — *Southern half*	11.39	12.29	10.86	34.54	11.51	16.66	10.99	39.16
Pohjoispuolisko — *Northern half*	5.61	3.88	2.88	12.37	4.88	3.33	2.47	10.68
Koko maa — *Whole country*	17.00	16.17	13.74	46.91	16.39	19.99	13.46	49.84

voidaan todeta, metsänparannustoiminta lisääntyi niin voimakkaasti 1960-luvulla, että metsätalouden suunnittelukomitean tavoitteet saavutettiin ja ylitettiin. Tästä syystä ja kasvun arvioimisen suurenemisen perusteella V inventoinnin tulosten valmistumisen yhteydessä suunnite suureni hieman yli 50 milj. m³:ksi ja pieneni Perä-Pohjolan alueen tultua arvioiduksi 49.84 milj. m³:ksi, joka on 2.93 milj. m³ suurempi kuin metsätalouden suunnittelukomitean mietinnössä esitetty suunnite ja 2.24 milj. m³ suurempi kuin V inventoinnin kasvun arvio.

Merkittävin ero aikaisempaan suunnitteeseen verrattuna edellä esitetyn lisäksi on, että maan eteläpuoliskon suunnite on 4.62 milj. m³ suurempi, pohjoispuoliskon suunnite 1.69 milj. m³ pienempi ja kuusen suunnite 3.82 milj. m³ suurempi. Eteläpuoliskon suunnitteen suureneminen johtuu kutakuinkin kokonaan kuusen osuuden suurenemisesta, jonka perusteena on taas kuusen kuutiomäärän ja kasvun arvioiden suureneminen. Tältä osalta ero metsätalouden suunnittelukomitean mietinnössä esitettyyn suunnitteeseen johtuu osaksi siitä, että kuusen osuus 1960-luvulle tehdyssä suunnitteessa perustui kuusen käytön ennusteelle, joka oli selvästi silloistakin kuusen kasvun arviota pienempi. Maan pohjoispuoliskon suunnitteen pienenemiseen on taas syynä puuston voimakas pieneneminen, joka on keskittynyt parhaille menekkialueille.

Perä-Pohjolan pienentyneisiin korjuumahdollisuuksiin on pääasiassa kaksi syytä. Korjuu 1950- ja 60-luvulla ei kohdistunut ensisijaisesti vanhimpiin metsikköihin, vaan Perä-Pohjolan eteläosan päätehakkuuiän saavuttaneisiin suhteellisesti nuorimpiin metsikköihin, mistä on seurauksena, että nykyisestä korjuukypsästä puustosta on huomattava osa pohjoisimmissa yli-ikäisissä ja hidaskasvuisissa metsiköissä ja taloudellisesti epäedullisissa menekkioloissa. Toinen syy pienentyneeseen suunnitteeseen on uusien metsiköiden hidas alkukehitys ja männyn viljelyn miltei täydellinen epäonnistuminen pääosalla aikaisempia kuusimaita. Tältä osalta 1950-luvun lopussa tehdyt arviot Perä-Pohjolan metsien tuotannollisista mahdollisuuksista ovat osoittautuneet liian suuriksi.

Taulukko 36. Tärkeimpien puutavaralajien osuudet suunnitteista V inventoinnin arvion mukaan.

Table 36. Proportions of principal timber assortments in the allowable drain.

Alue *Area*	Puulaji *Tree species*	Tukki [1] *Saw log*	Paperipuu [2] *Pulp wood*	Hukkapuu [3] *Waste wood*	Yhteensä *Total*
		% suunnitteesta — % *of allowable drain*			
Eteläpuolisko *Southern half*	Mänty — *Pine*	49	45	6	100
	Kuusi — *Spruce*	37	56	7	100
	Lehtip. — *Dec. spp.*	13	72	15	100
	Yhteensä — *Total*	34	57	9	100
Pohjoispuolisko *Northern half*	Mänty — *Pine*	42	49	9	100
	Kuusi — *Spruce*	27	61	12	100
	Lehtip. — *Dec. spp.*	1	72	27	100
	Yhteensä — *Total*	28	58	14	100
Koko maa *Whole country*	Mänty — *Pine*	47	46	7	100
	Kuusi — *Spruce*	35	57	8	100
	Lehtip. — *Dec. spp.*	11	72	17	100
	Yhteensä — *Total*	32	58	10	100

[1]) Tukkipuun pienin rinnankorkeusläpimitta 19.5 cm ja tukin pienin latvaläpimitta noin 6 tuumaa. — *Minimum breast height diameter of saw log tree 19.5 cm and minimum log top diameter approx. 6 inches.*

[2]) Pölkyn pienin latvaläpimitta 6 cm. — *Minimum log top diameter 6 cm.*

[3]) Hukkapuu sisältää hakkuutähteen ja luonnonpoistuman. — *Waste wood includes logging waste and mortality.*

Nykyisen suunnitteen tavoitteena on kuten aikaisemmankin arvokkaiden havupuiden osuuden lisääminen puustossa ja vähäarvoisen lehtipuun sekä suurelta osalta korjuukypsyyden saavuttaneen koivun vähentäminen. Tästä syystä männyn suunnite on 5 % ja kuusen suunnite 2 % kummankin puulajin kasvua pienempi sekä lehtipuun suunnite 34 % sen kasvua suurempi. Kuusen osalta on vielä otettava huomioon, että suunnite edellyttää kuusen vähentämistä maan pohjoispuoliskossa, jossa kuusen suunnite on 24 % sen kasvua suurempi. Syynä tähän on yli-ikäisen ja lahoavan kuusen runsaus sekä kuusen vähäisempi kasvu ja arvo mäntyyn verrattuna pohjoisessa.

Tärkeimpien puutavaralajien osuudet nykysuunnitteesta on esitetty taulukossa 36. Kuten puutavaralajien määritelmistä ilmenee, tukin osuus vallitseviin kauppatapoihin verrattuna on suunnitteessa aliarvioitu. Jos tukki erotetaan noin 5 tuuman latvaläpimittaan asti, rinnankorkeusläpimitaltaan alle 19.5 cm olevat minimitukin antavat rungot otetaan huomioon ja vanerikoivu korjataan keskimääräistä tukkia lyhyempinä rungon osina, niin tukkiosuuden ylärajaksi saadaan oheisessa asetelmassa esitetyt arviot, joihin on liitetty myös tukkiosuudet metsätalouden suunnittelukomitean mietinnön suunnitteesta:

	Tukkiosuus % suunnitteesta 1960	1970
Mänty	46	47—53
Kuusi	30	35—46
Lehtipuut	11	11—14
Yhteensä	30	32—40

Tukkiosuuden lisääntyminen hakkuumahdollisuusarviossa on seurausta aiemmin todetusta puuston järeyden lisääntymisestä. Pohjoispuoliskon osalta on kuitenkin syytä todeta, että inventoinnin tulosten mukaisessa mäntytukin osuudessa on runsaasti niin pieniä ja huonolaatuisia tukkeja, että niitä ei kaikkia nykyisessä puun niukkuuden ja paperipuun suuren tarpeen oloissa käytetä sahaukseen (T i i h o n e n 1971) ja että kuusitukin osuus on todennäköisesti yliarvioitu, koska vanhan kuusen kaikkia lahovikoja ei kyetä inventoinnissa havaitsemaan.

Liitetaulukossa 18 on esitetty V inventoinnin suunnite alkuperäisten perusteiden mukaan puutavaralajeiksi jaettuina yhdistelminä aikaisemmin piirimetsälautakuntien alueittain julkaistuista tuloksista. Tukin osalta liitetaulukon määrät vastaavat edellä esitettyä tukin prosenttiosuuden alarajaa.

V inventoinnin tulosten mukainen hakkuusuunnitteen jakautuminen omistajien kesken on esitetty taulukossa 37, jossa suunnite on kuorellisena puuna. Suunnitteen jakaantuminen noudattaa varsin tarkasti kasvun jakaantumista siitä huolimatta, että metsien ikärakenteen mukaan kokonaisuuden kannalta edullisin puuston kehittäminen edellyttäisi hakkuiden painottumista niihin metsiin, joissa on eniten vanhoja ja yli-ikäisiä metsiköitä. Toisaalta valtion vanhoista metsiköistä sijaitsee suuri osa pohjoisessa huonoissa menekki- ja uudistumisoloissa, suojametsäalueella ja kansallispuistojen laajentamissuunnitelmien kohteena, joten niitä ei ole realistista ottaa mukaan hakkuumahdollisuusarvioon pelkästään ikärakenteen ja puuston kehittämistavoitteen perusteella. Lisäksi valtion ja yhtiöiden metsissä on tähänastinen korjuu ollut kestävyyden ylittänyttä ja on todennäköistä, että kestävyyden ylittämistä ei enää tapahdu ainakaan samassa mitassa kuin aikaisemmin.

Hakkuumahdollisuusarvioiden osuuden kehittymisestä omistajittain voidaan esittää vain summittaisia tietoja (Kuva 20), koska suunnitteen harkinnanvaraiset perusteet ovat olleet erilaiset eri inventointien yhteydessä. Niinpä ensimmäisissä inventoinneissa hakkuumahdollisuusarviot perustuivat suurelta osalta metsiköittäin niiden metsänhoidollisen tilan mukaisiin hakkuuehdotuksiin ja myöhemmin suunnitteisiin ovat vaikuttaneet hakkuulaskelmien yhteydessä sovelletut puuston kehittämisen periaatteet. III inventoinnin tuloksissa esitettiin valtion metsille niiden vanhojen metsiköiden runsauden vuoksi suunnitetta, joka oli noin 45 % valtion metsien kasvua ja myös selvästi kestävää hakkuumäärää suurempi (I l v e s s a l o 1956). Eh-

Taulukko 37. Vuotuinen suunnite kuorellisena puuna puulajeittain ja omistajittain 1964—70.

Table 37. Annual allowable drain, including bark, of the growing stock by tree species and ownership categories in 1964—70.

Puulaji *Tree species*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*
	% suunnitteesta — *% of allowable drain*					Milj. m³ *Mill. m³* %
	Eteläpuolisko — *Southern half*					
Mänty — *Pine*	28.1	36.1	40.6	35.3	28.6	13.42
Kuusi — *Spruce*	42.7	43.2	38.4	43.1	42.8	19.39
Lehtip. — *Decid. spp.*	29.2	20.7	21.0	21.6	28.6	12.74
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	45.55
	Pohjoispuolisko — *Northern half*					
Mänty — *Pine*	42.9	46.9	47.6	58.3	55.0	5.70
Kuusi — *Spruce*	31.7	34.4	30.4	25.0	27.5	3.89
Lehtip. — *Decid. spp.*	25.4	18.7	22.0	16.7	17.5	2.95
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	12.54
	Koko maa — *Whole country*					
Mänty — *Pine*	30.3	37.1	45.5	37.7	42.7	19.12
Kuusi — *Spruce*	41.1	42.4	32.8	41.2	34.7	23.28
Lehtip. — *Decid. spp.*	28.6	20.5	21.7	21.1	22.6	15.69
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0	58.09
	Eteläpuolisko — *Southern half*					
Mänty — *Pine*	81.1	8.7	6.8	2.7	0.7	100.0
Kuusi — *Spruce*	85.3	7.2	4.4	2.3	0.8	100.0
Lehtip. — *Decid. spp.*	88.5	5.3	3.7	1.7	0.8	100.0
Yhteensä — *Total*	85.0	7.1	4.9	2.2	0.8	100.0
	Pohjoispuolisko — *Northern half*					
Mänty — *Pine*	50.2	2.6	42.1	1.2	3.9	100.0
Kuusi — *Spruce*	54.3	2.8	39.3	0.8	2.8	100.0
Lehtip. — *Decid. spp.*	57.3	2.0	37.6	0.7	2.4	100.0
Yhteensä — *Total*	53.1	2.5	40.2	1.0	3.2	100.0
	Koko maa — *Whole country*					
Mänty — *Pine*	71.9	6.9	17.3	2.2	1.7	100.0
Kuusi — *Spruce*	80.1	6.5	10.3	2.0	1.1	100.0
Lehtip. — *Decid. spp.*	82.7	4.6	10.1	1.5	1.1	100.0
Yhteensä — *Total*	78.1	6.1	12.5	2.0	1.3	100.0

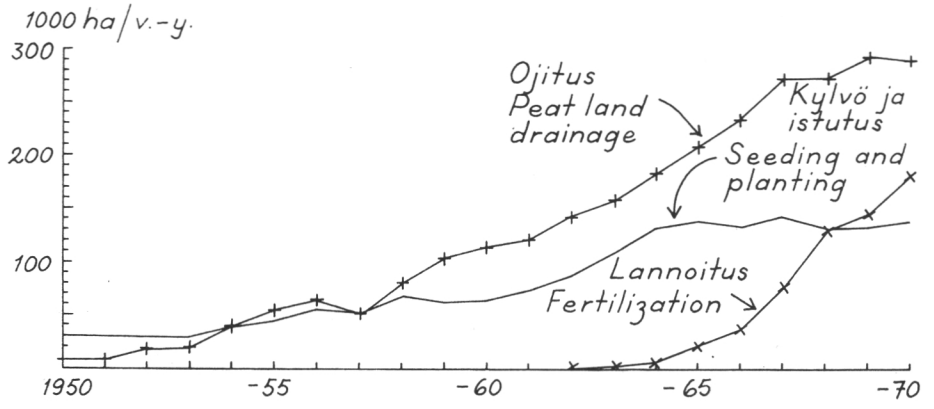
dotuksen perusteena oli ajatus, että valtion metsistä tulisi korjata vanhaa puustoa mahdollisimman paljon ennen suuria lahoamismenetyksiä ja yksityismetsien puustoa tulisi kartuttaa niiden nuoren iän ja pienen keskikuution vuoksi. Itse asiassa näin tapahtuikin 1950- ja 60-luvulla, kuitenkin niin, kuten aikaisemmin on todettu, että valtion metsien hakkuut eivät kohdistuneet ensisijaisesti vanhimpiin pohjoisimpiin metsikköihin.

V inventoinnin tuloksissa on valtion niin kuin muidenkin omistajien metsien suunnite pyritty arvioimaan kestävyyden periaatteen mukaan. Kuten seuraavassa luvussa lähemmin tarkastellaan, valtion metsätalouden suunnittelussa on viime aikoina otettu huomioon yhä enemmän hakkuita pienentäviä tekijöitä erityisesti Pohjois-Suomessa. Tästä syystä metsähallituksen metsien osuus 49.84 milj. m^3:n suuruisesta suunnitteesta on noin 13 % suurempi vuoden 1969 poistuman arviota (vert. s. 76).

Vielä on syytä todeta, että puun käyttötutkimuksen tuloksiin sisältyvästä 1 milj. m^3:n suuruisesta vuotuisesta luonnonpoistumasta tapahtuu suhteellisesti suurin osa valtion metsissä. Samoin valtion metsien osuus on lahoamaan jäävästä hakkuutähteestä suhteellisesti suurin. Tästä syystä suunnitteen käyttöpuusta yksityismetsien osuus on vielä suurempi kuin suunnitteen kokonaispoistumasta. Suuruusluokka-arvioina voidaan esittää, että suunnitteen käyttöpuuosuudesta on yksityismetsien osuus 81 %, yhtiöiden metsien 7 %, valtion 9 %, kuntien ja seurakuntien 2 % ja yhteisöjen 1 %.

Suunnitteen kestävyyden edellytykset

Suunnitearviot on tehty V inventoinnin edistyessä aina kunkin alueen tulosten käsittelyn yhteydessä ja ottamalla huomioon asianomaisen ajankohdan metsänhoidon ja perusparannustoiminnan laajuus ja laatu. Suunnitteen 49.84 milj. m^3 kuoretonta puuta kestävyys perustuu siten vuosina 1964—70 keskimäärin toteutettuun metsänhoitoon ja metsänparannukseen. Kuten kuvan 14 perusteella voidaan todeta, on metsänparannus jatkuvasti lisääntynyt 1960-luvun loppupuoliskolla ja erityisesti lannoituksen osalta.



Kuva 14. Metsänparannustöiden työsaavutusten kehittyminen.
Fig. 14. Development of the forest improvement works

Teoreettisten laskelmien mukaan 1960-luvun lopulla harjoitettu metsänhoito ja metsänparannus turvaisivat 1970-luvulla noin 52 milj. m³:n suuruisen suunnitteen kestävyyden (E r v a s t i ym. 1969, s. 7).

Nykysuunnitteen suurentamiselle 52 milj. m³:iin ei näytä kuitenkaan olevan realistisia edellytyksiä seuraavista syistä:

— Suuria metsäaloja on eri syistä puun tuotannon ulkopuolella eikä tilanne näiden alueiden osalta ole ainakaan paranemassa, kuten myöhemmin lähemmin todetaan. Tällaisia alueita on lounaisessa ja eteläisessä saaristossa ja rannikolla sekä itäisillä ja varsinkin pohjoisilla alueilla. Maan eteläpuoliskossa oli V inventoinnin aikana sellaista metsämaata, jossa ei havaittu mitään hakkuun jälkiä 131 000 ha ja sellaista metsämaata, jossa viimeisen hakkuun jäljet arvioitiin yli 30 vuotta vanhoiksi, oli 733 000 ha. Vastaavat metsämaan alat pohjoispuoliskossa olivat 1 419 000 ha ja 1 682 000 ha. Yhteensä voidaan sanoa säännöllisen korjuutoiminnan ulkopuolella olleen 3.9 milj. ha eli 21.2 % metsämaan alasta.

— Ojitetusta pinta-alasta oli V inventoinnin tulosten mukaan noin 30 % pääasiassa harvan ojaston vuoksi tilassa, joka ei vastannut tavoitteena olevaa ojitustulosta. Vuoteen 1971 mennessä ojitetusta alasta se on 1.5 milj. ha.

— Viljelyllä perustetuista metsiköistä arvioitiin 19 % liian harvoiksi ja täydennystä tarvitseviksi. Vuoteen 1971 mennessä viljellystä pinta-alasta tämä osuus on 323 000 ha.

— Metsänparannuksen tavoiteohjelmissa edellytetään, että lannoitus tulisi suunnata kasvua eniten lisäävästi puustoisiin metsikköihin. V. 1969 lannoituksista, yhteensä 146 000 ha, suoritettiin 73 % turvemailla ja pääasiassa laihojen ojitettujen turvemaiden perusparannuksena.

— Vajaatuottoiseksi arvioitujen metsiköiden suuri määrä, 18.8 % metsämaasta eli 3.5 milj. ha, puuttoman uudistusalan osuus 4.4 % eli 822 000 ha ja kasvatettavien metsiköiden harvuus tavoitepuuston metsiköihin verrattuna merkitsevät sitä, että puuston käsittely ei tapahdu suuren puun tuoton edellyttämällä tavalla. Lisäksi metsissä on hakkuutoiminnankin piirissä havaittavissa puun tuotantoa pienentävää yli-ikäistymistä (vert. Kuvat 6 a—c), joka on laajoilla alueilla lisääntymässä.

Edellä esitettyjen tekijöiden vuoksi ei ole perusteltua olettaa, että 49.84 milj. m³:n suuruinen suunnite aliarvioisi kestäviä korjuumahdollisuuksia. Päin vastoin korjuumahdollisuuksien vajaa hyväksikäyttö laajoilla alueilla maan eteläpuoliskossa, valtion metsissä puun korjuun viimeaikainen

kehittyminen kasvuakin pienemmäksi, pyrkimykset laajentaa kansallispuistoja ja hakkuilta kokonaan rauhoitettuja alueita sekä ympäristönsuojelussa yleistyvä pyrkimys säilyttää laajoja alueita vajaassa puun tuotannossa uhkaavat pienentää merkittävästi kestävää suunnitetta siitä, miksi se fyysisteknillisten tekijöiden perusteella arvioitiin 1960-luvun lopussa. Näiden pyrkimysten vaikutuksesta ehdittiin suorittaa arvioita V inventoinnin yhteydessä Perä-Pohjolan alueella, minkä lisäksi havaintoja voidaan esittää myös maan eteläpuoliskosta, josta tarkempia arvioita saadaan lähitulevaisuudessa VI inventoinnin tulosten yhteydessä.

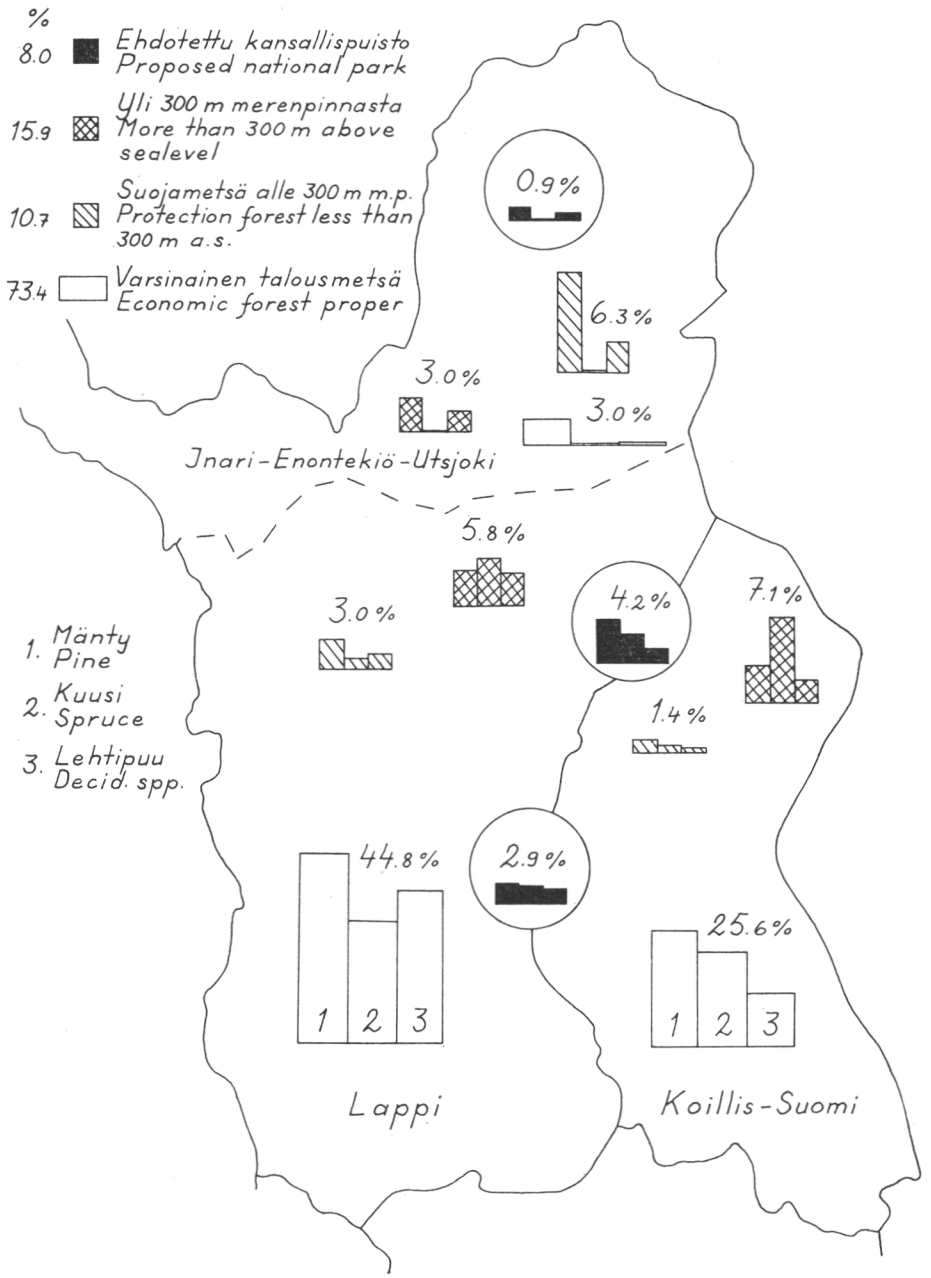
V inventoinnin maan eteläpuoliskoa koskevien tulosten (K u u s e l a 1970) ja talousneuvostolle valmistetun Suomen puuntuotantomahdollisuuksien selvityksen yhteydessä (E r v a s t i ym. 1969) on todettu, että eteläpuoliskon metsävaroja on rasitettu epätasaisesti. Pääasiassa suurten vesistöjen latva-alueilla on suoritettu kestävyyden ylittäneitä hakkuita ja toisaalta meren rannikolla ja rannikkoon liittyvissä maakunnissa kaikkia kestäviä korjuumahdollisuuksia ei ole käytetty hyväksi. Ellei tätä tasapainottomuutta saada poistetuksi, arvioitiin sen kestävää suunnitetta pienentävä vaikutus noin 3 milj. m³:ksi.

Maan pohjoispuoliskon eteläosassa ja varsinaisesti Kainuussa itärajaan liittyvällä alueella on metsiä, joiden ikänsä puolesta olisi pitänyt joutua hakkuiden kohteeksi aikaisemmin kuin ne lähempänä tehtaita ja kuljetusväyliä sijainneet, uudistuskypsyyden saavuttaneet metsiköt, jotka on uudistettu. Tältä osalta tilanne on vielä kärjistyneempi Perä-Pohjolassa, jossa jäljellä olevat kiertoajan saavuttaneet ja suurelta osalta sen ylittäneet uudistuskypsät metsiköt keskittyvät alueen pohjoisimpiin osiin, suojametsäalueelle ja sen läheisyyteen (Taulukko 38 ja Kuva 15). Näillä pohjoisimmilla alueilla on uudistuskypsien metsiköiden osuus 55—60 % metsämaan alasta, kun se varsinaisten talousmetsien alueella on noin 35 %.

Taulukko 38. Suunnitteen 5.37 milj. m³ jakaantuminen valtion ja muiden omistajien metsiin sekä laki- ja suojametsien osuus suunnitteesta Lapin ja Koillis-Suomen piirimetsälautakunnan alueella.

Table 38. Allowable drain of 5.37 mill. m³ by state forests and forests of other owners and in high hills and protection forests in forestry board districts of Lappi and Koillis-Suomi.

Puulaji *Tree species*	Valtio *State*		Muut omistajat *Other owners*		Yhteensä *Total*		Laki- ja suojam. *High hills and protec. forests*	
	Milj. m³ *Mill. m³*	%	Milj. m³ *Mill. m³*	%	Milj. m³ *Mill. m³*	%	Milj. m³ *Mill. m³*	%
Mänty — *Pine*	1.26	52.7	1.13	47.3	2.39	100.0	0.67	28.0
Kuusi — *Spruce*	0.65	41.9	0.90	58.1	1.55	100.0	0.42	27.1
Lehtip. — *Dec. spp.*	0.67	46.9	0.76	53.1	1.43	100.0	0.34	23.8
Yhteensä — *Total*	2.58	48.0	2.79	52.0	5.37	100.0	1.43	26.6



Kuva 15. Hakkuusuunnitteen 5.37 milj. m³ alueellinen ja vyöhykkeittäinen jakaantuminen Lapin ja Koillis-Suomen piirimetsälautakuntien alueella.

Fig. 15. Allowable drain of 5.37 mill. m³ by areas and zones in forestry board districts of Lappi and Koillis-Suomi.

Erilaisten periaatteiden vaikutuksesta Perä-Pohjolan hakkuumahdollisuuksiin voidaan esittää seuraavat neljä vaihtoehtoa:

1. Jos suunnite on 5.37 milj. m³, joka on Perä-Pohjolan osuus 49.84 milj. m³:n suuruisesta koko maan suunnitteesta, niin laki- ja suojametsät kuuluvat luontaista uudistamista käyttävän hakkuutoiminnan piiriin ja uusia kansallispuistoja ja muita puun tuotannon ulkopuolelle jätettäviä alueita ei perusteta. Suunnitteeseen ei sisälly teollisuuspuun hakkuita pääosalla pohjoisimpia kitumaita ja osalla harvapuustoisia metsämaita.
2. Jos suunnite on 4.80 milj. m³, niin edellä esitettyjen rajoitusten lisäksi yli 300 m merenpinnan yläpuolella sijaitsevat lakimetsät ovat pääosaksi teollisuuspuun hakkuiden ulkopuolella ja suojametsien hakkuut ovat varovaisia ja niiden kasvua selvästi pienempiä. Tämä vaihtoehto vastaa valtion metsien osalta likimain metsähallituksen soveltamia periaatteita vuoden 1970 tienoilla.
3. Jos suunnite on 4.50 milj. m³, niin edellä esitettyjen rajoitusten lisäksi voidaan perustaa ne kansallispuistot ja muut rauhoitusalueet, joista vuonna 1970 oli periaatesuunnitelmat valtion luonnonsuojelunvalvojan toimistossa, ja jotka käsittivät metsä- ja kitumaata noin 0.5 milj. ha.
4. Jos suunnite on 3.80 milj. m³, niin kaikki laki- ja suojametsät voidaan jättää hakkuutoiminnan ulkopuolelle ja edellä todetut kansallispuistot ja rauhoitusalueet voidaan perustaa.

Yhteenvetona edellä esitetystä voidaan todeta, että jos tähänastinen puun tuotantomahdollisuuksien vajaa hyväksikäyttö jatkuu ja jos maan pohjoispuoliskossa toteutetaan pyrkimykset jättää suuri määrä kasvatettua puusatoa korjaamatta ja lahoamaan, niin kestävä suunnite joudutaan koko maan osalta pienentämään noin 46 milj. m³:iin. Tämäkin on liian suuri kestäväksi poistumaksi, jos eteläisimmässä osassa maata toteutuu useissa yhteyksissä esitetty tarve säilyttää kasvatettua puusatoa korjaamatta osana ympäristöä. Korjuumahdollisuuksien pienenemisen kansantaloudellisesta merkityksestä saa käsityksen arviosta, jonka mukaan jos poistuman pieneneminen 1 milj. m³ vuodessa pienentää teollisuuspuun määrää noin 0.8 milj. m³, niin vuoden 1970 hinnoilla vientitulo pienenee 140 milj. mk. Suunnitteen pieneneminen 46 milj. m³:iin vastaa vientitulojen pienenemistä noin 530 milj. mk vuotta kohti.

Puutase

Puutaseen osia ovat puuston kuutiomäärä, kasvu, poistuma ja suunnite. Niitten toisiinsa vertaaminen edellyttää niiden arvioimista samakäsitteisesti ja samalla mittayksiköllä. Puuston kuutiomäärä on elävien puiden runkojen

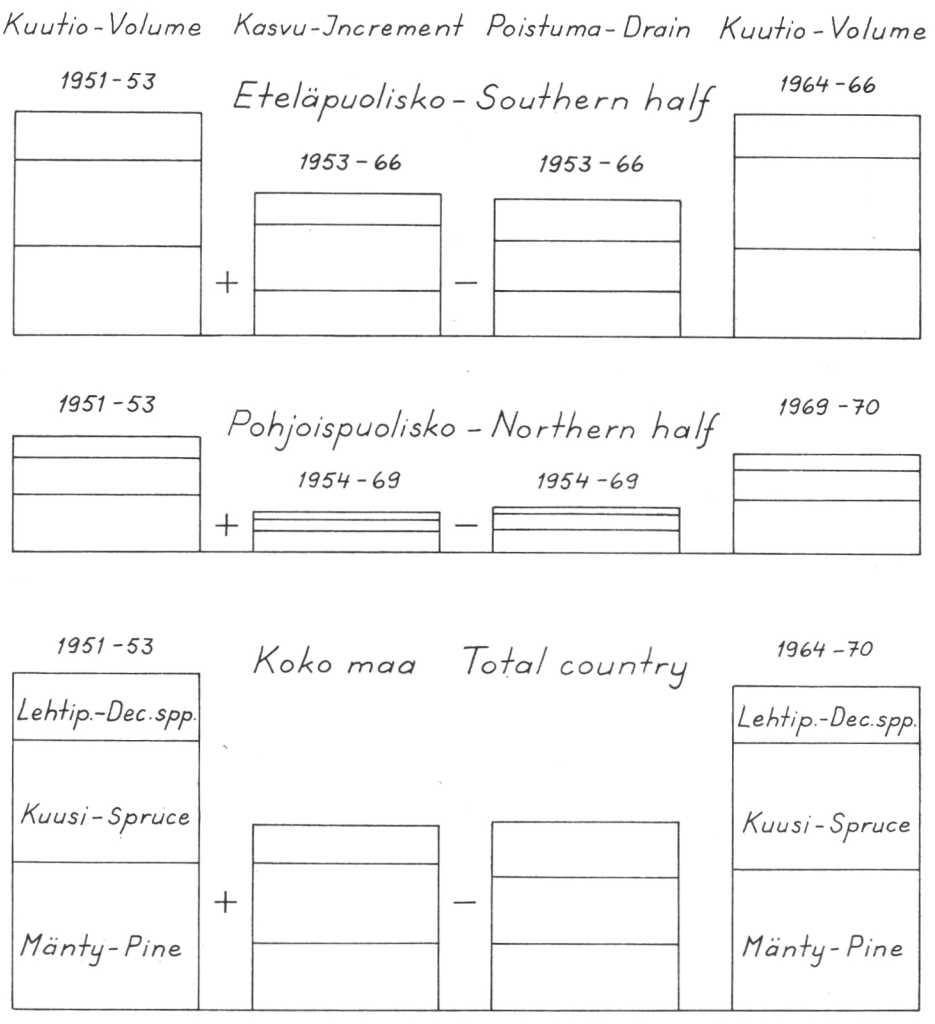
Taulukko 39. Kuutiomäärän, kasvun ja poistuman arvioiden luotettavuusvertailu.
Table 39. Reliability comparision of volume, increment and drain estimates.

Puutaseen osat *Parts of timber balance*	Mänty *Pine*	Kuusi *Spruce*	Lehtipuut *Decid.spp.*	Yhteensä *Total*
	Eteläpuolisko — *Southern half*			
1. Kuutio — *Volume 1951—53* ...	329.3	319.5	175.6	824.4
2. Kasvu — *Increment a, b*[1])	176.4 | 170.4	193.2 | 246.8	121.8 | 112.4	491.4 | 529.6
3. Poistuma — *Drain 1953—66* ...	166.3	192.5	156.3	515.1
4. 1.+2.—3.	339.4 | 333.4	320.2 | 373.8	141.1 | 131.7	800.7 | 838.9
5. Kuutio — *Volume 1964—68* ...	327.3	349.9	160.1	837.3
6. 100 4./5.	103.7 | 101.9	91.5 | 106.8	88.1 | 82.3	95.6 | 100.2
	Pohjoispuolisko — *Northern half*			
1. Kuutio — *Volume 1951—53* ...	218.5	129.7	79.0	427.2
2. Kasvu — *Increment a, b*[1])	84.8 | 81.4	49.6 | 42.9	40.0 | 32.0	174.4 | 156.3
3. Poistuma — *Drain 1954—69* ..	86.1	54.9	34.6	175.6
4. 1.+2.—3.	217.2 | 213.8	124.4 | 117.7	84.4 | 76.4	426.0 | 407.9
5. Kuutio — *Volume 1964—68* ...	206.0	104.5	66.9	377.4
6. 100 4./5.	105.4 | 103.8	119.0 | 112.6	126.1 | 114.2	112.9 | 108.1
	Koko maa — *Whole country*			
1. Kuutio — *Volume 1951—53* ...	547.8	449.2	254.6	1 251.6
2. Kasvu — *Increment a, b*[1])	261.2 | 251.8	242.8 | 289.7	161.8 | 144.4	665.8 | 685.9
3. Poistuma — *Drain 1954—69* ...	252.4	247.4	190.9	690.7
4. 1.+2.—3.	556.6 | 547.2	444.6 | 491.5	225.5 | 208.1	1 226.7 | 1 246.8
5. Kuutio — *Volume 1964—68* ...	533.3	454.4	227.0	1 214.7
6. 100 4./5.	104.4 | 102.6	97.8 | 108.2	99.3 | 91.7	101.0 | 102.6

[1]) a = valtakunnan metsien III ja b = V inventoinnin kasvun arvio. — *a = increment estimated in 3. and b = increment estimated in 5. inventory.*

tilavuus, kasvu elävien puiden runkojen tilavuuden suurenemista, poistuma elävästä puustosta korjattujen ja luontaisesti kuolleiden runkojen tilavuus ja suunnite perusteittensa mukainen tulevan poistuman arvio. Yksikkönä on kuutiometri kuoretonta puuta, joskin viime aikoina on lisääntynyt tarve käyttää kuorellista puuta, koska puuta kuljetetaan entistä enemmän kuorellisena käyttöpaikkaansa ja kuorestakin on tulossa raaka-aine. — Aiemmin yleisesti käytetty nimitys ko. vertailulle on ollut metsätase. Puutase on parempi sen vuoksi, että vertailu sisältää vain puumääriä.

Puutasetta voidaan tarkastella useaakin eri tarkoitusta silmällä pitäen. Tässä yhteydessä verrataan puuston kuutiomäärän, kasvun ja poistuman arvioita toisiinsa niiden keskinäisen luotettavuuden toteamiseksi, kasvua ja poistumaa toisiinsa päätelmien tekemiseksi puuston kehittymisestä ja kasvua, poistumaa ja suunnitetta toisiinsa puun käytön ja korjuumahdollisuuksien vertaamiseksi sekä lähitulevaisuuden puutaseen ennakoimiseksi. Puuston, kasvun ja suunnitteen kuutioarviot perustuvat III ja V inventoinnin tuloksiin ja poistuman arviot puun käyttötutkimusten tuloksiin (esim. Ervasti ja Kuusela 1968; Huttunen 1971). Erityisesti on syytä korostaa, että inventointi- ja puun käyttötutkimukset ovat toisistaan riippu-



Kuva 16. Puuston, kasvun ja poistuman luotettavuusvertailu III ja V inventoinnin sekä puun käyttötutkimusten tulosten perusteella.
Fig. 16. Reliability comparision of the growing stock, increment and drain estimates on the basis of the results of the 3rd and 5th inventory and wood consumption investigation.

mattomia kaikilta muilta osiltaan paitsi poistuman ja suunnitteen luonnonpoistuman osalta siten, että tämä erä perustuu samaan suuruusluokkaarvioon. Luonnonpoistuman osuus on kuitenkin kokonaispoistumasta vain 2 %.

Puuston, kasvun ja poistuman arvioiden keskinäistä luotettavuutta on V inventoinnin osittaisten tulosten perusteella jo tarkasteltu aikaisemmin (K u u s e l a and E r v a s t i 1969). Tässä esitetään yhteenveto III ja V inventoinnin välisestä ajasta koko maan ja etelä- sekä pohjoispuoliskon osalta (Taulukko 39 ja Kuva 16). Vertailussa on otettava huomioon arvioissa

mahdolliset satunnais- ja systemaattiset virheet, joita on lähemmin tarkasteltu edellä mainitussa julkaisussa.

Vertailussa käytetään menettelyä, jossa alkukuutiona 1. (Taulukko 39) on III inventoinnin arvio. Siihen lisätään kahtena vaihtoehtona III inventoinnin (2. a) ja V inventoinnin (2. b) kasvun arvio kerrottuna inventointien välisen ajanjakson vuosien lukumäärällä. Summasta vähennetään puun käyttötutkimuksen tulosten mukainen saman ajanjakson poistuma 3. Erotus 1. + 2. — 3. on laskennallinen puuston kuutiomäärä jakson lopussa kahtena vaihtoehtona, joita verrataan V inventoinnin tuloksena saatuun puuston kuutiomäärän arvioon 5. siten, että jälkimmäisen suhteellinen arvo on 100. Jos vertaustulos 6. on 100, arviot ovat keskenään ristiriidattomat; jos se on suurempi kuin 100 ja jos puuston kuutiomäärän arviot oletetaan virheettömiksi, niin joko kasvun arvio on liian suuri tai poistuman arvio liian pieni; jos taas se on pienempi kuin 100, niin samalla edellytyksellä joko kasvun arvio on liian pieni tai poistuman arvio liian suuri.

Erottamatta puulajeja inventointi- ja poistumatutkimuksen tulokset muodostavat maan eteläpuoliskossa erittäin hyvin yhtä pitävän ja luotettavan kokonaisuuden, jonka merkitsevyyttä varmentaa aikaisemmin suoritettu piirimetsälautakuntien alueittainen tarkastelu (K u u s e l a ja E r v a s t i 1969). Tuloshan merkitsee sitä, että ko. ajanjakson poistuma tai vaihtoehtoisesti kasvu on laskettavissa näistä toisen tunnuksen ja inventointien tulosten mukaisten puuston kuutiomäärän arvioiden perusteella.

Maan eteläpuoliskossa puulajeittaisessa vertailussa esiintyy sen sijaan eroja, jotka ovat ilmeisestikin merkitseviä ja johtuvat joko poistuman tai kasvun arvioiden virheistä. Jos poistuman arviot oletetaan virheettömiksi, niin V inventoinnissa saatu kuusen kasvun arvio on liian suuri ja lehtipuiden kasvun arvio liian pieni. Vaikka käyttötutkimuksen menetelmän perusteella onkin ilmeistä, että puulajeittaisten poistumien luotettavuus on suhteellisesti heikompi kuin kokonaispoistuman arvio, niin todetut erot perustunevat ainakin osittain inventoinnissa käytettyyn likimääräisen tuloksen antavaan, mittausjakson aikana poistuneiden puiden kasvun arvioimiseen. Mittausjakson aikana poistuneiden puiden kasvua arvioitaessa on kaikkia puulajeja pidetty yhtenä kokonaisuutena, joka menettely puulajien kasvun ja poistuman todellisten suhteiden perusteella yliarvioi kuusen ja aliarvioi lehtipuiden kasvua sekä antaa tältä osalta männylle likimain oikean kasvun arvion. Männyn arvioiden yhtäpitävyys eteläpuoliskossa onkin erittäin hyvä. Tämän enempää vertailun perusteella on tuskin mahdollista päätellä, vaan on odotettava luotettavampaa tarkistusta toistuvien inventointien tulosten keskinäisestä vertailusta.

Maan pohjoispuoliskossa arvioiden ristiriita on niin suuri, että sitä on pidettävä merkitsevänä, ts. puuston kuutiomäärä on pienentynyt enemmän kuin mitä kasvun ja poistuman arvioiden perusteella olisi pitänyt tapahtua.

Kuitenkin kasvun mittauksen kannalta helpoimman puulajin männyn osalta yhtäpitävyys on niin hyvä, että laskennallisen kuutiomäärän eroa +3.8 % inventoinnilla saadusta loppukuutiosta ei voida pitää satunnaisvirheen mahdollisuuden puitteissa merkitsevänä.

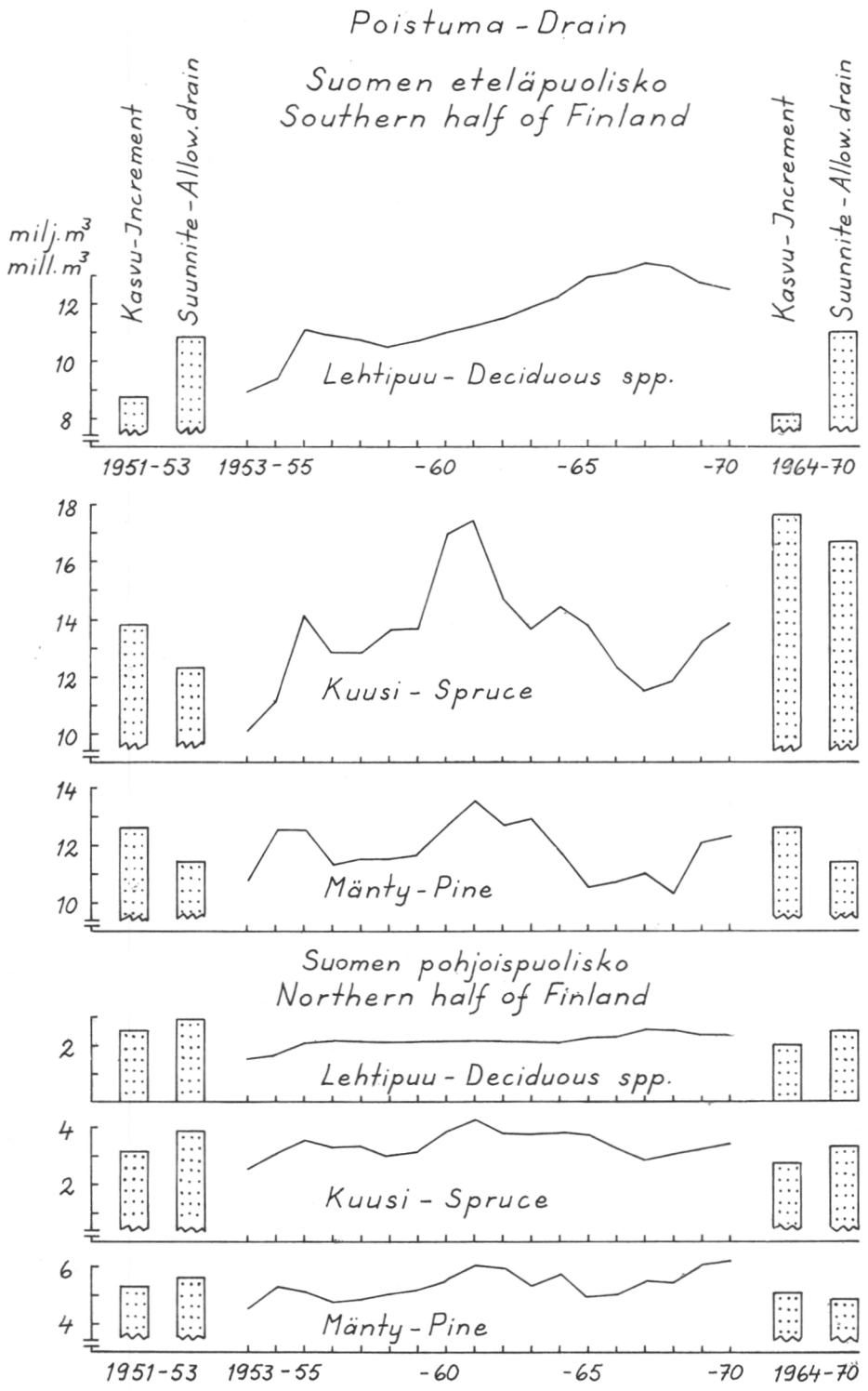
Mahdollisia virhelähteitä voivat olla kuusen ja lehtipuiden kasvun vaikea mitattavuus, hakkuutähteiden ja luonnonpoistuman suuri osuus sekä kahden viimeksi mainitun tunnuksen arvioimisen vaikeus. Niinpä hukkapuuta on vuoden 1969 poistuman arviossa maan pohjoispuoliskossa 20 % eli 2.33 milj. m³. Koko maan 1 milj. m³:n suuruisesta luonnonpoistuman arviosta on myös pääosa pohjoispuoliskon osuutta. Vertailun tulos antaa aiheen epäillä, että pohjoispuoliskon laaja-alaisissa hakkuiden ulkopuolelle jääneissä yli-ikäisissä luonnonmetsissä luonnonpoistuma voi olla huomattavastikin laskelmissa käytettyä arviota suurempi.

Kokonaisuutena edellä esitetystä puuston, kasvun ja poistuman vertailusta voidaan todeta, että ottamalla huomioon olosuhteet, tutkimusten yleiset edellytykset ja tehtävän luonne, niin inventointi- ja puun käyttötutkimuksen muodostaman kokonaisuuden tuloksia on pidettävä hyvinä. Tuskin missään muualla yhtä laajaperäisen metsätalouden olosuhteissa ja samalla määrällä tutkimusvaroja on saatu yhtä luotettavia puutaseen perustietoja metsä- ja puutalouden kehittämiseksi kuin Suomessa.

Aikajakson 1951—70 kasvun, suunnitteen ja poistuman arvioiden perusteella (Kuvat 17 ja 18) voidaan todeta maan eteläpuoliskon osalta, että lehtipuun poistuman keskimääräinen arvio vuosina 1953—66 on ollut 11.2 milj. m³ ja vuosina 1967—70 13.0 milj. m³, kun nykyinen suunnitteen arvio on 11.0 milj. m³. Suunnitteen ylitys oli suurimmillaan yli 2 milj. m³. Kun verrataan kasvun, poistuman ja suunnitteen arvioita toisiinsa ja otetaan huomioon, että 1960-luvun loppuun sattui puunjalosteiden menekin nousukausi, niin lehtipuun poistuman arvion pieneneminen voinee merkitä vain alkanutta lehtipuun hakkuumahdollisuuksien ja tarjonnan pienenemistä. Tunnusten suhteet nykyisellään johtavat lehtipuuston osuuden nopeutuvaan pienenemiseen puustossa.

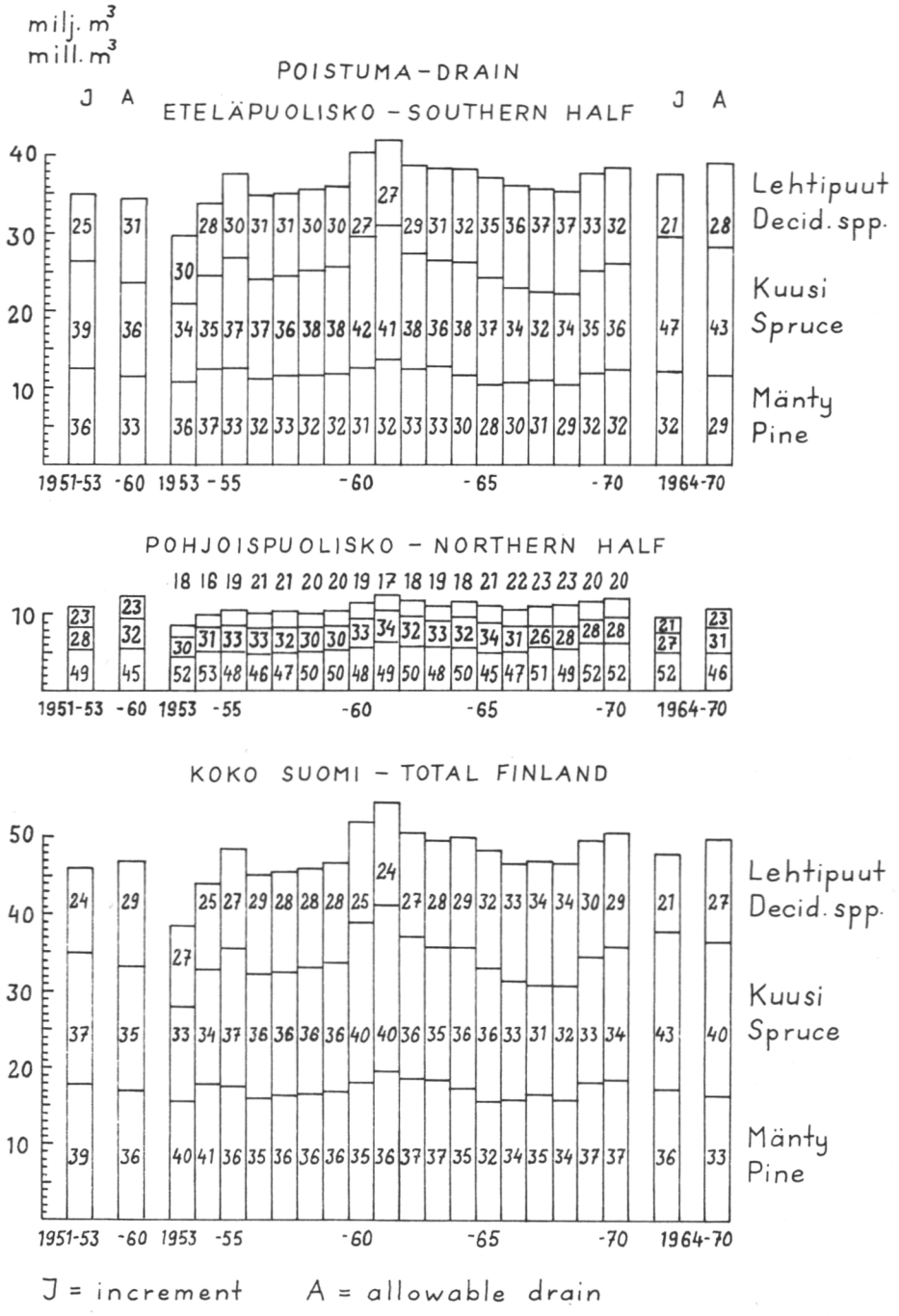
Kuusen keskimääräinen poistuma maan eteläpuoliskossa oli vuosina 1953—66 13.8 milj. m³ ja vuosina 1967—70 12.6 milj. m³. Nykysuunnite on 16.7 milj. m³. Kuusen hakkuumahdollisuudet on täysin käytetty hyväksi vain suuren paperipuun viennin aikana 1960-luvun alussa. Tämä näyttäisi viittaavan siihen, että kuusen pieni poistuma kasvuun ja suunnitteeseen verrattuna johtuu pääasiassa kotimaisen kysynnän vähäisyydestä. Puutaseen ja metsävarojen kehittämisen kannalta sen pitäisi suureta tulevaisuudessa. Taseen jatkuminen nykyisenä johtaa kuusen osuuden voimakkaaseen lisääntymiseen puustossa.

Männyn keskimääräinen poistuma on maan eteläpuoliskossa ollut vuosina 1953—66 11.9 milj. m³ ja vuosina 1967—70 11.4 milj. m³. Kun nykysuunnite



Kuva 17. Kasvu, suunnite ja poistuma puulajeittain maan etelä- ja pohjoispuoliskossa vuosina 1951—70.

Fig. 17. Increment, allowable drain and drain by tree species in Southern and Northern half of the country in 1951—70.



Kuva 18. Kasvun, suunnitteen ja poistuman määrä ja rakenne maan etelä- ja pohjoispuoliskossa sekä koko maassa vuosina 1951—70.

Fig. 18. Volume and structure of increment, allowable drain and drain in Southern and Northern half and whole of the country in 1951—70.

on 11.5 milj. m^3, on tase likimain tasapainossa. Poistuman viimeaikainen kehittyminen viittaa siihen, että männyn tarjontaan saattavat tähänastiset suuret hakkuut ja niiden alueellinen erilaisuus vaikuttaa jo pienentävästi.

Kokonaisuutena maan eteläpuoliskossa keskimääräinen poistuma on vuosina 1953—66 ollut 36.8 milj. m^3 ja vuosina 1967—70 37.0 milj. m^3. Kun suunnite on 39.2 milj. m^3, niin metsävarojen kannalta poistumaa voitaisiin suurentaa runsaat 2 milj. m^3. Muutoksen tulisi tapahtua siten, että kuusen poistuma suurenisi noin 3 milj. m^3 ja lehtipuun pienenisi noin 1 milj. m^3.

Maan pohjoispuoliskossa lehtipuun ja kuusen poistuma on 1960-luvun lopulla ollut likimain suunnitteen suuruutta, mikä johtaa näiden puulajien vähenemiseen puustossa. Männyn poistuma oli vuosina 1954—69 keskimäärin 5.4 ja v. 1970 6.2 milj. m^3. Nykysuunnite on 4.8 milj. m^3. Kestävyyden turvaamiseksi ja puuston rakenteen parantamiseksi poistuman tulisi pienetä vajaat 1.5 milj. m^3 ja pienenemisen tulisi kohdistua yksin omaan mäntyyn. Kuten aiemmin on todettu, männyn ylihakkuu on varsinaisesti kohdistunut Perä-Pohjolan metsiin. Edellisen luvun perusteella on myös pääteltävissä, että näinkin pienennetyn poistuman korjaaminen voi tuottaa vaikeuksia.

Puutaseen arviot osoittavat, että III inventoinnin tulosten perusteella arvioitu pohjoispuoliskon suunnite oli 12.4 milj. m^3. Vuosien 1954—69 poistuma oli keskimäärin 11.0 milj. m^3 ja vuoden 1970 poistuma 12.0 milj. m^3. Ts. puun käyttö ei ole johtanut 1950-luvun lopulla arvioitua suunnitetta suurempaan poistumaan.

1950- ja 60-luvulla toteutettu hakkuutoiminta ei ole kohdistunut suunnitteiden edellyttämällä tavalla Pohjois-Suomen vanhimpiin metsikköihin. Metsien uudistumisen nopeus ja todennäköisesti myös ojituksen vaikutus eivät ole olleet niin edullisia kuin aikanaan arvioitiin. Nykyisten tietojen valossa onkin ilmeistä, että 1950-luvun lopulla yliarvioitiin maan pohjoispuoliskon puuntuotantomahdollisuuksia. Voimaperäisen puun tuotannon ja taloudellisesti kannattavan korjuun edellytykset ovat osoittautuneet Lapin ilmasto- ja kuljetusoloissa suunnitteiden perustana olleita käsityksiä heikommiksi. Vaikka aikaisempien suunnitteiden kestävyydellä on ollut edellytyksiä, joita ei ole toteutettu, niin nämä suunnitteet ovat puoltaneet 1960-luvun alussa aloitettuja teollisuuden laajennuksia. Toisaalta teollisuuden laajentuminen ei pysähtynyt vielä 1960-luvun puolivälissä, jolloin 1960—63 suoritetun IV inventoinnin tulokset osoittivat, mitkä pohjoispuoliskon puun tuotantomahdollisuudet todellisuudessa olivat.

Koko maan osalta, kuitenkin edellisessä luvussa esitetyin varauksin, puutase on 1960-luvulla saavutettuun puun käytön ja poistuman tasoon verrattuna tasapainossa. Männyn poistumaa tulisi pienentää noin 1.5 milj. m^3 ja samalla määrällä tulisi poistuman pienetä pohjoispuoliskossa. Lehtipuun poistuman tulisi eteläpuoliskossa pienetä noin 1 milj. m^3. Nämä muu-

tokset tulisi korvata suurentamalla kuusen poistumaa eteläpuoliskossa. Puun käytön suurentamisen kannalta myönteisempi puutase on saatavissa vain nykyisestään olennaisesti laajennetulla metsänparannuksella ja pääasiassa lannoituksella.

Puutaseen puutavaralajeittaisen vertailun osalta on tässä yhteydessä tarpeen kiinnittää huomiota tukin osuuteen ja sen viime aikaiseen käyttöön sekä suunnitteesta jäävään teollisuuspuuhun. Aikaisemmin kuvatun suunnitteen tukkiosuuden ja vuoden 1970 puun käytön saha- ja vaneritukkiosuuden vertailu on seuraavassa asetelmassa:

	Suunnitteessa tukkia		Poistumassa tukkia	
	%	milj. m³	%	milj. m³
Mänty	47—53	7.7— 8.7	49	9.0
Kuusi	35—46	7.0— 9.2	29	5.0
Lehtipuu	11—14	1.5— 1.9	14	2.2
Yhteensä	33—40	16.2—19.8	32	16.2
Poistuma		49.8		50.7

Kun otetaan huomioon, että järeän puun käyttö vuoden 1970 noususuhdanteessa oli keskimääräistä suurempaa, niin voidaan todeta, että suunnitteen rakenne turvaa hyvin järeän puun tarpeen. Sen sijaan lehtipuun kokonaismäärän vähäisyydestä suunnitteessa seuraa, että lehtipuutukkia on suunnitteessa vähemmän kuin mikä on teollisuuden tuotantotehoa vastaava tarve. Samasta syystä on suunnitteen mäntytukin määrä tarvetta pienempi maan pohjoispuoliskossa. Järeätä kuusta on suunnitteessa runsaasti verrattuna saha- ja vaneritukkien käyttöön. Toisaalta paperiteollisuus on jo v. 1970 käyttänyt noin 2.5 milj. m³ kuusitukkia.

Kun suunnitteesta vähennetään muut kuin teollisuuspuuerät, niin jäännöksen ja vuoden 1970 kotimaisen teollisuuspuun käytöstä saadaan seuraava vertailu:

	Teollisuuspuujäännös suunnitteesta	Teollisuuspuu poistumassa
	milj. m³	
Mäntyä	13.9	15.6
Kuusta	17.1	14.4
Lehtipuuta	3.3	5.6
Yhteensä	34.3	35.6

Kun jälleen otetaan huomioon, että vuoden 1970 poistuma oli suhdannehuipun vuoksi keskimääräistä suurempi, niin vertailun perusteella voidaan tehdä likimain samat puutasetta koskevat päätelmät kuin aikaisemmin puulajeittaisen vertailun yhteydessä.

Eri omistajien metsien suunnitteen ja poistuman vertailu voidaan tehdä likimääräisenä metsähallituksen, osakeyhtiöiden ja niiden eläkesäätiöiden sekä muiden osalta, koska nämä ovat ainoat omistajat, joiden osalta pois-

Taulukko 40. Kasvun, suunnitteen ja v. 1969 poistuman likimääräinen vertailu omistajaryhmittäin.
Table 40. Approximative comparision of increment, allowable drain and drain in 1969 by ownership groups.

	Metsähallitus *National Board of Forestry*	Osakeyhtiöt ja eläkesäätiöt *Companies and their foundations*	Muut *Others*	Yhteensä *Total*	
	%				Milj. m³ *Mill. m³*
	Eteläpuolisko — *Southern half*				
Kasvu — *Increment*	4.7	7.7	87.6	100.0	37.83
Suunnite — *Allow. cut*	4.5	7.5	88.0	100.0	39.16
Poistuma — *Drain, 1969*	3.7	6.6	89.7	100.0	37.91
	Pohjoispuolisko — *Northern half*				
Kasvu — *Increment*	40.0	2.8	57.2	100.0	9.77
Suunnite — *Allow. cut*	39.2	2.7	58.1	100.0	10.68
Poistuma — *Drain, 1969*	32.3	3.3	63.4	100.0	11.69
	Koko maa — *Whole country*				
Kasvu — *Increment*	11.9	6.7	81.4	100.0	47.60
Suunnite — *Allow. cut*	12.0	6.5	81.5	100.0	49.84
Poistuma — *Drain, 1969*	10.7	5.8	83.5	100.0	49.60

tuma on arvioitu. Tämä vertailu on esitetty taulukossa 40, jossa on vuoden 1969 poistuman arvio ja pinta-alasuhteiden perusteella lasketut kasvun ja suunnitteen arviot.

Taulukon 40 perusteella voidaan todeta, että metsähallituksen osuus vuoden 1969 poistumasta on suhteellisesti pienempi kuin sen metsien osuus sekä suunnitteen että kasvun arviosta. Kun otetaan huomioon, että metsähallituksen metsille tehtyjen suunnitteiden mukaan poistuman tulisi olla pienenevä, niin voidaan todeta, että metsien sijainnin ja niihin kohdistettujen ns. moninaiskäyttövaatimusten vuoksi metsähallituksen metsien poistuma saattaa jäädä pysyvästi kasvua pienemmäksi. Valtion vanhojen ja yli-ikäisten metsien runsauden vuoksi tämä merkitsee suuria lahoamismenetyksiä jo kasvatetussa puusadossa ja puun tuotantomahdollisuuksien vajaata hyväksikäyttöä.

Yhtiöiden metsien poistuma v. 1969 oli myös pienempi kuin V inventoinnin tulosten mukainen suunnite. Tämä johtunee siitä, että yhtiöt ovat pienentäneet hakkuita aikaisemmin suoritettujen voimakkaiden hakkuiden vastapainoksi.

Muiden omistajien, pääasiassa yksityisten metsistä v. 1969 poistuma on ollut niiden suunniteosuutta suurempi ja erityisesti maan pohjoispuoliskossa, jossa näinkin suuri suunnitteen ja kasvun ylitys jatkuvana johtaisi kestävyyden ylittävään liikahakkuuseen. Mikäli valtion metsien hakkuutoiminta jatkuu nykyisellään maan pohjoispuoliskossa, pienenee puun kokonaistarjonta ennemmin tai myöhemmin alle nykysuunnitteen.

METSIEN LAATU JA HAKKUIDEN TOISTUVUUS

Metsiköiden laatua (aikaisemman nimityksen mukaan metsänhoidollista tilaa) kuvaavan luokituksen tulokset on esitetty taulukossa 41 ja liitetaulukossa 19 sekä vertailu III ja IV inventoinnin tuloksiin koko maan osalta taulukossa 42. Kuten monissa yhteyksissä on todettu, metsiköiden laadun ja erityisesti vajaatuottoisen metsikön käsitteet ovat epätäsmällisiä ja käytännössä usein subjektiivisia. Tämä on todettavissa taulukosta 42. On myös esitetty, että metsiköiden laadun luokituksesta pitäisi luopua, koska tulokset ovat vaikeasti tulkittavia ja toistuvien inventointien osalta ristiriitaisia. Luokitus on kuitenkin säilytetty, pääasiassa sen vuoksi, että sen tulokset sisältävät jotain käytännölle arvokasta tietoa. Kullekin ajankohdalle näyttää olevan ominaista omat hyvää metsänhoitoa koskevat käsitykset. Niiden mukainen luokitus antaa suurpiirteisen kuvan metsien laadusta ja ohjeita metsänhoidon kehittämiselle.

Taulukko 41. Metsiköiden laadun eroja yksityisten, yhtiöiden ja valtion metsissä 1964—70.

Table 41. Differences in the tree stand quality in private, company and state forests 1964—70.

Laatu — *Quality*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Koko maa *Whole country*
	% metsämaasta — % *of forest land*			
Hyvä ja tyydyttävä — *Good and satisfactory*	60.9	78.4	65.2	63.8
Harsien harvennettu — *Treated by selection cutting*	6.5	2.0	2.1	5.0
Muu kehityskelpoinen — *Other capable for development*	13.2	10.0	11.7	12.4
Yhteensä kehityskelpoiset — *Total capable for development*	80.6	90.4	79.0	81.2
Harsintajäte — *Residual of selection cutting*	6.0	2.0	2.8	4.8
Kasvupaikalle väärä puulaji — *Tree species unsuitable for site*	6.2	2.7	5.4	5.7
Yli-ikäinen — *Over-aged*	0.7	0.1	6.9	2.2
Muu vajaatuottoinen — *Other low-yielding*	6.5	4.8	5.9	6.1
Yhteensä vajaatuottoiset — *Total low-yielding*	19.4	9.6	21.0	18.8
Yhteensä — *Total*	100.0	100.0	100.0	100.0

Taulukko 42. Metsiköiden laatu metsämaalla (kasvullisella metsämaalla 1951—53).
Table 42. Quality of the stands on forest land (on productive forest land 1951—53).

Laatu — *Quality*	1951—53	1960—63	1964—70
	% alasta — % *of area*		
1. Hyvä — *Good*	15.6	13.1	21.5
2. Tyydyttävä — *Satisfactory*	25.8	39.3	42.3
3. Harsien harvennettu — *Treated by selection cutting*	19.0	4.8	5.0
4. Hoitoa vaille jäänyt — *Silvicultural measure neglected*	20.8	23.0	10.2
5. Lepoa tarvitseva — *To be leaved uncut*	4.3	1.8	2.2
1.—5. Kehityskelpoiset — *Capable for development*	85.5	82.0	81.2
6. Harsintajäte — *Residual of selection cutting*	4.4	1.7	4.8
7. Kasvupaikalle väärä puulaji — *Tree species unsuitable for site*	6.4	11.3	5.7
8. Yli-ikäinen — *Over-aged*	1.9	1.3	2.2
9. Muu vajaatuottoinen — *Other low-yielding*	1.8	3.7	6.1
6.—9. Vajaatuottoiset — *Low-yielding*	14.5	18.0	18.8
1.—9. Yhteensä — *Total*	100.0	100.0	100.0
1.—9. Yhteensä 1 000 ha — *Total 1 000 ha*	17 352	19 452	18 697

Vajaatuottoisuuden käsitteestä on erityisesti syytä todeta, että siltä osalta arvioinnin tarkoituksena on selvittää niiden metsiköiden määrä ja tärkeimmät ryhmät, jotka on edullisempaa uudistaa aikaisemmin kuin ne saavuttavat ohjekiertoajan mukaisen uudistamiskypsyyden. Ryhmään kuuluvat myös aukeat uudistusalat, joilla kasvupaikalle sopivan puulajin luontainen uudistuminen on epävarmaa tai viivästyvää ja joilla viljely on uudistamisen ajankohtana suorittamatta. Nämä ns. vajaatuottoiset uudistusalat sisältyvät ryhmään »muu vajaatuottoinen» ja niiden osuus nykyisen laajan uudistamisen aikana on 2—3 % metsäalasta.

Vajaatuottoisuuden käsite on inventoinneissa muuttunut ennen muuta seuraavilta osiltaan: Käsitteen tultua ensimmäisen kerran käyttöön vajaatuottoisuus katsottiin pääasiassa hakkuiden aiheuttamaksi. Huonokin hakkuun jälki voitiin hyväksyä, jos metsikkö arvioitiin luontaisesti uudistuvaksi. Alussa ei myöskään pidetty vähäarvoista lehtipuumetsikköä vajaatuottoisena, jos puiden rungot olivat suoria ja niistä saatiin halkoa.

Inventointi inventoinnilta on voimistunut käsitys, jonka mukaan arvioinnin ajankohdan puustoa verrataan kasvupaikalle arvokkaimman puulajin muodostamaan täysitiheään metsikköön ja vajaatuottoisuus ratkaistaan tämän vertailun perusteella. V inventoinnissa päähuomio kiinnitettiin metsikön tukkituotokseen, koska se antaa valtaosan kantorahatuloista. Yleisohjeena oli esim., että tiheydeltään välttävässä metsikössä tulee olla arvokkaiden puiden, so. pääasiassa tukkirunkojen tai sellaiseksi varttuvien pohjapinta-ala vähintään 60 % harvennuksen jälkeisen täysitiheän, hyvän metsikön pohjapinta-alasta.

Kun III inventoinnissa suorarunkoiset ja tiheät lepiköt sekä hieskoivikot saattoivat vielä olla kehityskelpoisia, niin V inventoinnissa lehtipuuvaltaisista arvioitiin kehityskelpoisiksi vain riittävän tiheät rauduskoivuvaltaiset metsiköt. On myös todennäköistä, että kuivien ja kivikkoisten kankaiden kuusikot on luokitettu V inventoinnissa aikaisempaa johdonmukaisemmin vajaatuottoisiksi. Ts. vajaatuottoisuuden käsite on muuttunut siten, että V inventoinnissa on arvioitu vajaatuottoisiksi myös sellaisia metsiköitä, jotka aikaisemmin on arvioitu kehityskelpoisiksi.

Vajaatuottoisuuden määritelmästä ei seuraa, etteikö edullisessa runkojen siirtymän vaiheessa olevaa vajaatuottoista metsikköä kannattaisi kasvattaa ohi tämän siirtymän vaiheen. Ts. riukuvaiheen hieskoivikko on edullisempi kasvattaa paperipuukokoon kuin uudistaa välittömästi. Sama koskee kuivan kankaan riukuvaiheen kuusikkoa. Oleellista on, että puuston huonon laadun tai alhaisen tiheyden vuoksi metsikön kasvatusikä on edullisinta jättää hyvän metsikön ohjekiertoaikaa lyhyemmäksi.

Taulukon 42 perusteella voidaan todeta, että kehityskelpoisten metsiköiden laatu on parantunut selvästi viimeksi kuluneiden 20 vuoden aikana. Tämä johtuu alaharvennuksen luontoisten kasvatushakkuiden yleistymisestä ja ne mahdollistaneesta pinotavaran menekin paranemisesta. Puustoa pilaavat tukkipuiden harsinnat ovat olennaisesti vähentyneet. Kun otetaan huomioon tukkipuun ja paperipuun suuri kantohintaero ja siitä aiheutuva »kiusaus» suorittaa harsintoja, on hakkuutapojen paranemista pidettävä yksityismetsälain mukaisen edistämis- ja valvontatoiminnan merkittävänä saavutuksena. Konkreettisena seurauksena tästä on voimakkaasta puun korjuusta huolimatta tapahtunut tukkipuuston lisääntyminen.

Vajaatuottoisten alueiden pinta-ala on lisääntynyt siitäkin huolimatta, että V inventoinnin tuloksissa on »muun vajaatuottoisen» ryhmässä 2—3 %-yksikköä viljelyä odottavaa aukeaa uudistusalaa. Osaksi tämä johtuu arvostelun kiristymisestä, mutta uutta vajaatuottoista alaa on tullut ainakin laitumien ja peltojen sekä osaksi ojitettujen soiden metsittyessä luontaisesti vajaatuottoiseksi metsiköksi. Harsintahakkuut aiheuttavat myös vielä jonkin verran vajaatuottoisia metsiköitä.

Vaikka vajaatuottoisuus onkin suurelta osalta historiallista perintöä kaskien, metsälaitumien ja vähäisen paperipuun menekin ajoilta, niin sen säilyvyys osoittaa, että pitkävaikutteisten metsänparannustöiden toteuttamista ja rahoitusta ei oltu onnistuttu ratkaisemaan V inventoinnin ajankohtaan mennessä. Sikäli kuin yksityismetsistä on kysymys, yksityismetsälaki ei velvoita uudistamaan sellaista vajaatuottoista metsikköä, jota ei ole välittömällä hakkuulla aikaan saatu.

Metsiköiden laatua koskevat arviot tärkeimpien omistajien metsissä osoittavat, että metsänhoidollinen tila on suhteellisesti paras yhtiöiden metsissä. Tämä on ilmeisestikin seuraus yhtiöiden metsissä toteutetusta laajasta

hakkuutoiminnasta ja sen yhteydessä täytäntöön pannusta metsänhoidosta ja metsänparannuksesta. Valtion metsissä niiden laajuuden ja erämaaluonteen vuoksi tulokset eivät ole yhtä hyviä. Yksityisten metsistä on havaittavissa jo edellä todettu perusparannuksen hidas liikkeelle lähtö ja suurempi alttius harsintahakkuisiin kuin muiden omistajien metsillä (yksityiskohtaisemmat tulokset liitetaulukossa 19).

Viljelyllä perustettujen metsiköiden määrää ja laatua osoittavan karkean luokittelun tulos on esitetty taulukossa 43 (yksityiskohtaisemmin liitetaulukossa 20). Viljelyllä perustettuja metsiköitä on inventoinnin ajankohtana ollut 1.2 milj. ha. Kun otetaan huomioon myöhemmin suoritetut viljelyt, niin vuonna 1971 on ollut noin 1.7 milj. ha viljelyllä perustettuja metsiköitä. Suhteellisesti eniten on viljelty yhtiöiden metsissä, joiden pinta-alasta 16.6 % oli viljelemällä perustettuja inventoinnin ajankohtana. Vastaava suhdeluku oli pienin varsinaisissa yksityismetsissä, 4.7 % ja koko maassa keskimäärin 6.4 %.

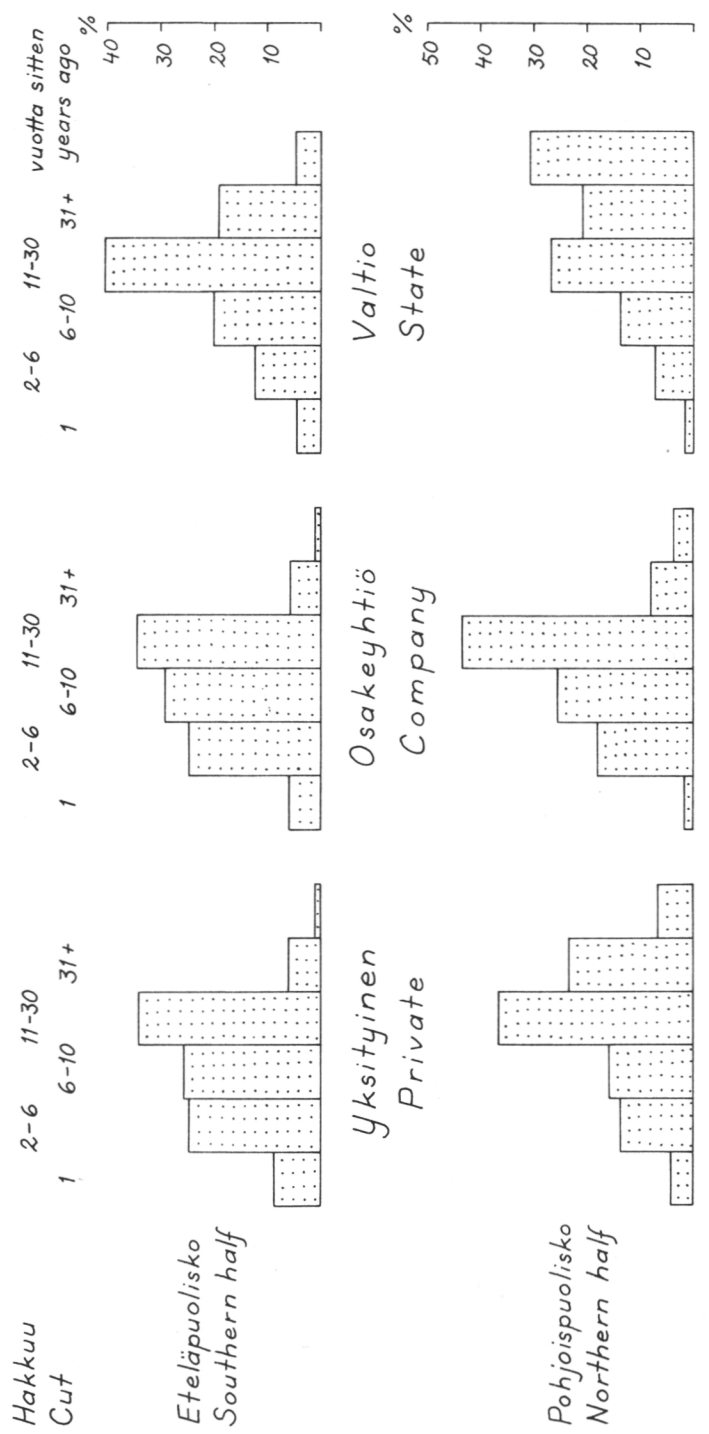
Viljelytaimistojen suurin heikkous on liika harvuus. Koko maassa arvioitiin täydennysviljelyä tarvittavan 224 000 ha:lla eli 18.6 %:lla viljellystä alasta. Tämä suhdeluku oli suurin yksityisten metsissä, 25.3 %, ja toiseksi suurin valtion metsissä, 22.8 %. Viljelytaimistojen harvuutta valtion metsissä selittää niiden pohjoinen sijainti. Valtion maiden viljelymetsiköistä oli 71 % maan pohjoispuoliskossa.

Sikäli kuin viljelytaimistojen laatu kuvaa metsänhoidon tasoa, niin suurista omistajista metsänhoidon taso on selvästi parhain yhtiöiden metsissä ja huonoin yksityisten metsissä. Muitten pieniä aloja käsittävien omistajien kohdalta tietoihin on voinut vaikuttaa sattumanvaraisuus, mutta ne näyttä-

Taulukko 43. Viljelyllä perustetut metsiköt ja niiden laatu yksityisten, yhtiöiden ja valtion metsissä 1964—70.
Table 43. Artificially established tree stands and their quality in private, company and state forests in 1964—70.

Omistaja *Owner*	Metsikön laatu — *Quality of stand*					Yhteensä *Total*	Metsämaasta *Of forest land*
	1	2	3	4	5		
	1 000 ha ja % — *1 000 ha and %*						
Yksityinen — *Private*	381	18	110	35	30	574	—
	66.4	3.1	19.2	6.1	5.2	100.0	4.7
Osakeyhtiö — *Company*	177	2	29	3	19	230	—
	76.9	0.9	12.6	1.3	8.3	100.0	16.6
Valtio — *State*	242	5	78	1	21	347	—
	69.7	1.4	22.5	0.3	6.1	100.0	8.0
Koko maa — *Whole country*	833	25	224	41	77	1 200	—
	69.5	2.1	18.6	3.4	6.4	100.0	6.4

1. Hyvä tai tyydyttävä taimisto. — *Good or satisfactory seedling and sapling stand.*
2. Hoitamaton taimisto. — *Untended seedling and sapling stand.*
3. Täydennettävä männyn (tai koivun) taimisto. — *Seedling and sapling stand of pine (or birch) in need of supplementary planting.*
4. Täydennettävä kuusen taimisto. — *Seedling and sapling stand of spruce in need of supplementary planting.*
5. Taimistoa varttuneempi metsikkö. — *Stand older than in seedling and sapling stage.*



Kuva 19. Viimeisestä hakkuusta kulunut aika metsämaalla yksityisten, osakeyhtiöiden ja valtion metsissä.
Fig. 19. Time from the last cut on forest land in private, company and state forests.

vät edustavan keskimääräistä parempaa metsänhoitoa. Kokonaisuutena näyttää siltä, että yksityinen metsänomistaja on vähiten altis suorittamaan kustannuksia vaativia metsänhoidollisia toimenpiteitä.

V inventoinnissa arvioitiin jokaisella kuviolla viimeisestä hakkuusta kulunut aika. Vaikka ja varsinkin kaukaisimpien hakkuiden osalta tulokset eivät voi olla kovin tarkkoja, ne antavat kuitenkin tietoa hakkuiden toistumisesta ja niiden eroista eri alueilla ja eri omistajien metsissä (Kuva 19 ja Liitetaulukko 21).

Kuten edeltäkäsin on odotettavissa, hakkuut toistuvat Etelä-Suomessa useammin kuin Pohjois-Suomessa ja useammin muiden omistajien kuin valtion metsissä. Pohjoispuoliskossa oli metsämaasta 18.3 % sellaista, jossa ei voitu havaita mitään hakkuun jälkiä ja 21.7 % sellaista, jossa hakkuun jäljet arvioitiin yli 30 v. vanhoiksi. Vastaavat arviot valtion mailla olivat 30.4 ja 20.6 % eli yhteensä 51 %. Maan eteläpuoliskossa hakkaamaton alue oli 1.2 % ja hakkuun jäljet yli 30 v. vanhoja 6.7 %:lla metsämaan alasta.

Kun pohjoispuoliskossa otetaan huomioon suuri kitu- ja joutomaan pinta-ala (metsämaata 7.8 ja kitu- sekä joutomaata 6.1 milj. ha), jossa hakkaamattoman ja yli 30 v. sitten hakatun alan osuus on vielä paljon suurempi kuin metsämaalla, niin voidaan todeta, että viimeaikaisista voimakkaista hakkuista huolimatta alkuperäistä erämaaluontoa on vielä paljon jäljellä. Eteläpuoliskossa se on sen sijaan suhteellisesti paljon vähäisempää ja keskittynee valtakunnan itärajan läheisyyteen ja meren saaristoon.

Maan pohjoispuoliskossa hakkuilla koskematon metsämaan ala oli 1.4 milj. ha ja yli 30 v. sitten hakattu ala 1.7 milj. ha. Tämä johtuu siitä, että korjuukustannusten kurissa pitämiseksi hakkuut ovat olleet keskitettyjä. Hakkuiden toistumisen pitkästä aikavälistä ja ennen muuta metsiköiden luonnontilaisuudesta on kuitenkin seurauksena suuri luonnonpoistuma. Näyttääkin todennäköiseltä, että puutaselaskelmissa 1 milj. m^3:n suuruinen luonnonpoistuma on valtaosalta juuri edellä todetuilla alueilla. Pohjoispuoliskon puutaseen kannalta ja myös avohakkuita seuraavan metsänviljelypaineen keventämiseksi olisi erittäin suotavaa, jos luonnontilaisia ja lähes sellaisia metsiköitä voitaisiin mahdollisimman laajasti käsitellä kuolevia ja lahoavia puita korjaavilla vahvojen väljennysten luontoisilla hakkuilla. Työvoimapoliittisesti tämä lienee vielä toistaiseksi mahdollista ja myös suotavaa niin kauan kuin samoilla alueilla on työtöntä väestöä.

Luonnonpoistuman mahdollisimman tarkan talteenoton kannalta tehokkaimmin ovat metsiään käsitelleet yhtiöt, kunnat, seurakunnat ja yhteisöt sekä heikoimmin valtio, mikä viimeksi mainittu ei johdu kokonaan omistuksen luonteesta vaan myös metsien sijainnista. Poikkeuksen tekevät pohjoispuoliskon yhteismetsät, jotka on muodostettu suurelta osalta valtion metsien hakkaamattomista alueista ja joissa korjuu ei ole vielä ehtinyt yhteismetsien yleisen voimaperäisyyden tasolle.

PÄÄTELMIÄ

Metsäpinta-ala pieneni tarkastelun kohteena olevana aikana 1920—70 aina 1950-luvun lopulle asti pääasiassa maatalousmaan mutta myös teiden, teollisuus- ja asutuskeskusten lisääntymisen vuoksi. Pienimmillään metsätalouden maan osuus, sisältäen metsä-, kitu- ja joutomaan sekä metsätalouden tiet, oli noin 77 % ja metsämaan ala noin 63 % maa-alasta. Vastaavat osuudet ovat nyt 79 ja 68 %. Maatalouden maan pieneneminen alkoi 1950-luvulla pellon ja metsän rajalla olevien laitumien metsittymisenä ja 1960-luvun lopulla maataloustuotteiden omavaraisuuden tultua saavutetuksi varsinaisten peltojen metsittymisenä. Näin tapahtuva metsätalouden maan lisääntyminen on ilmeisestikin ollut jo jonkin aikaa suurempaa kuin liikenneväylien ja asutuskeskusten lisääntyessä tapahtunut metsätalouden maan pieneneminen.

Viime aikoina tehtyjen arvioiden mukaan maataloustuotteiden omavaraisuus voidaan ylläpitää 1960-luvun loppupuoliskon tilanteeseen verrattuna noin 700 000 ha pienemmällä peltopinta-alalla. Maataloustuotannon jatkuvasti voimaperäistyessä, epäedullisimmilla alueilla sijaitsevien tilojen autioituessa ja yleisen tuotannollisen kehityksen jatkuessa on todennäköistä, että maatalouden maa pienenee ainakin edellä todetun määrän kuluvan vuosisadan loppuun mennessä. Puun tuotannon kannalta on kuitenkin epäedullista se, että maatalouden maan pieneneminen tapahtuu pääosaksi alueiden heitteille jäämisenä ja luontaisena metsittymisenä vajaatuottoisiksi metsiköiksi, ellei maapolitiikassa ja metsänparannuksessa päästä nykyistä parempaan toimintaan.

Merkittävin metsämaan lisääntyminen tapahtuu soiden ojituksen kautta. V inventoinnin ajankohtana oli metsämaan turvemaita 3.9 milj. ha, kun III inventoinnin ajankohtana kasvullisia turvemaita oli 3.3 milj. ha. Ottamalla V inventoinnin ajankohtana todetut ja sen jälkeen tilastoidut ojitukset huomioon, voidaan metsätalouden maan ojitusten pinta-alaksi arvioida vuoden 1971 lopussa noin 4.3 milj. ha. Ojitus etenee 250 000—300 000 ha:n vuosivauhdilla ja Mera-ohjelman mukainen valtakunnallinen tavoite on 7.4 milj. ha ojitettua turvemaata. Jos ojitusohjelma ja maatalousmaan metsittyminen tapahtuu tässä esitetyn mukaisesti, niin vuosisadan lopussa metsämaata on noin 23 milj. ha eli 75 % maa-alasta.

Jo pitkän aikaa suoritetun ojituksen merkityksestä saa summittaisen

käsityksen, jos oletetaan suuruusluokaltaan oikeaksi arvio, että ilman ojitusta metsien kasvu olisi 4 milj. m^3 pienempi kuin nyt. Tämän puumäärän käyttöpuuosuus raakapuuna ja jalosteena vuoden 1970 tilanteessa merkitsee lähes 600 milj. mk:n suuruista vientituloa.

Puulajivaltaisuuden pitkäaikaiselle kehittymiselle on maan eteläpuoliskossa ollut ominaista mäntyvaltaisten metsiköiden väheneminen, joka on pysähtynyt metsänviljelyn yleistyessä 1960-luvulla; kuusivaltaisten selvä lisääntyminen aluksi tervanpolton, kaskien ja kulojen jälkeen syntyneiden lepikoiden, koivikoiden ja männiköiden kuusettumisena, jota sahateollisuuden valtakaudella harsintana suoritettu puun korjuu edisti; ja lehtipuuvaltaisten metsiköiden nopeutuva väheneminen.

Maan pohjoispuoliskossa on mäntyvaltaisuus lisääntynyt ja varsinkin metsänhoidon yleistyessä kuusi- ja lehtipuuvaltaisten metsiköiden kustannuksella.

Koko maassa mäntyvaltaisten metsiköiden osuus on hitaasti suureneva, kuusivaltaisten osuus säilyy joko ennallaan tai suurenee hitaasti riippuen siitä, miten nopeasti pohjoispuoliskon kuusivaltaisia metsiköitä muutetaan männiköiksi. Lehtipuuvaltaisten metsiköiden osuus on kaikkien puulajien osalta pienenevä.

Puuston ikärakenteelle 1920-luvulla olivat ominaisia nuorten ja keskiikäisten metsiköiden runsaus maan eteläpuoliskossa ja vanhojen metsiköiden runsaus maan itä- ja pohjoisosissa. Sahateollisuuden valtakaudella vanhimmat ikäluokat vähenivät selvästi ja harsinnat sekä kuusettuminen nuorensivat puustoa ilman aukean alan kautta syntyneitä taimistoja. 1950- ja 1960-luvulla koko maan tultua säännöllisen paperipuun kysynnän piiriin ja alaharvennusten luontoisten kasvatushakkuiden yleistyttyä, yleisin ikäluokka 41—60 vuotta muuttui ikäluokaksi 61—80 vuotta, uudistaminen vähensi vanhimpia ikäluokkia ja lisäsi taimistoja. Uusista metsiköistä, joita ilmaantuu päätehakkuualueiden lisäksi myös uudelle metsämaalle, on suurin osa männiköitä. Kuusikoita syntyy myös runsaasti, sen sijaan lehtipuuvaltaisia taimistoja ja varsinkin rauduskoivikoita hyvin vähän.

Koska puuston nuorentuminen tapahtuu useaa tietä päätehakkuiden, alikasvosten vapauttamisen, ojitettujen alojen ja vapautuvan maatalousmaan metsittymisen kautta, niin uusien taimistojen ilmaantumisesta voi esittää vain likimääräisen arvion. Ikärakenteen ja metsämaan lisääntymisen perusteella voidaan arvioida, että vuotta 1967 edeltäneenä 15 vuotena on ilmaantunut noin 3.2 milj. ha uusia alle 40 vuotiaita metsiköitä, joista viljelyllä perustettuja on 1.1 milj. ha eli noin 34 %. Ottaen huomioon uudistumisen lisääntymisen, suojuspuuasentojen suhteellisen runsauden ja metsien yleisen harvuuden voidaan arvioida, että tällä hetkellä syntyy uusia nuoria metsiköitä 300 000—350 000 ha vuodessa, josta määrästä

viljelyn osuus on enintään 40 %. Metsänviljelykausi sanan täydessä merkityksessä on siten vielä suurten ponnistusten takana, jos siihen yleensä halutaan päästä.

Vaikka puuston nuorentuminen onkin voimakkaasti käynnissä, niin toisaalta ennen 1950-lukua tapahtuneen vähäisen uusien taimistojen muodostumisen seuraukset ovat kasautumassa vanhojen metsien runsaudeksi myös maan eteläpuoliskossa, jossa 61—80 vuotiaat metsiköt ovat runsain ikäluokka ja jossa 80—90 vuoden kiertoajan ylittäneitä metsiköitä on 20—25 % metsämaan alasta. Uudistuskypsien, suojuspuuasentojen ja vajaatuottoisten metsiköiden osuus kuutiomäärästä on 35—40 %. Kun myös pohjoispuoliskon vanhojen metsiköiden runsaus otetaan huomioon, niin ikä- ja kehitysluokkarakenne merkitsee toisaalta runsaita päätehakkuumahdollisuuksia nyt ja lähitulevaisuudessa sekä toisaalta vanhojen, kasvuaan pienentävien ja lahoamistappioita lisäävien metsiköiden kasautumista. Tämä puun tuotannon kannalta epäedullinen kehitys on torjuttavissa vain lisäämällä metsänparannusta niin paljon, että vanheneva puusato voidaan korjata ajoissa vaarantamatta puun tuotannon kestävyyttä.

Yhtäpitävästi ikärakenteen kehittymisen kanssa ovat kehittyneet puuston järeyssuhteet. Aluksi järeän puuston osuus kuutiomäärästä pieneni 1920- ja 1930-luvulla, mutta alaharvennusten yleistyttyä on järeän puuston osuus selvästi suurentunut kaikkialla muualla paitsi Perä-Pohjolassa, jossa järeitä runkoja lisäävien ikäluokkien määrä on hyvin pieni. Kuutiomääräsuhteiden muuttuminen huomioon ottaen järeän puuston lisääntyminen koskee ennen muuta kuusta, mutta myös mäntyä maan eteläpuoliskossa. Vähintään 20 cm rinnankorkeusläpimitaltaan olevien puiden osuus puuston kuutiomäärästä on 56 % ja se suurenee vielä ainakin 1970-luvulla. Eri puutavaralajien kantohintasuhteet ja puuston järeyden vaikutus korjuukustannuksiin huomioon ottaen puuston arvo on lisääntynyt olennaisesti viimeisten 20 vuoden aikana.

Puuston kuutiomäärä, joka V inventoinnin tulosten mukaan on 1 448 milj. m^3 kuorellista puuta, pieneni aluksi hieman 1920-ja 1930-luvulla, suureni 1940-luvulla ja 1950-luvun alkupuolella pääasiassa sodan vuoksi pienentyneiden hakkuiden johdosta ja alkoi hitaasti pienetä 1960-luvulla poistuman ylitettyä kasvun. Mikäli poistuman suuruus olisi 1970-luvulla suhdanteista riippuen 47—50 milj. m^3 vuotta kohti, jonka suuruiseksi se vakiintui 1960-luvun loppupuoliskolla, niin kuutiomäärän pieneneminen jatkuu. Näillä edellytyksillä ja metsänparannuksen jatkuessa nykyisellään on odotettavissa, että kuutiomäärän suureneminen alkaa 1980-luvulla. Mikäli taas puun tarjonta tekee mahdolliseksi ensiasteisen jalostustuotannon jatkuvan kasvun eikä metsänparannus olennaisesti lisäänny, voi puuston kuutiomäärän pieneneminen jatkua nopeammin ja pitempään, jolloin se myös vaarantaa kestävyyden.

Puulajien kuutiomääräosuuksille on ollut ominaista männyn osuuden hidas pieneneminen, joka jatkunee niin kauan kunnes uusien nuorten männiköiden suureneva kasvu tulee kuvaan mukaan, kuusen osuuden selvä ja jatkuva lisääntyminen sekä lehtipuiden osuuden voimistuva väheneminen. On mahdollista, että kuusesta tulee 1970-luvulla kuutiomääräosuudella mitattuna pääpuulaji nykyisen männyn sijalle.

Kuutiomäärän alueellisessa jakaantumisessa on tapahtunut puuston painopisteen siirtymistä etelään, lounaaseen ja länteen. Nykyisestä puuston kuutiomäärästä on Itä- ja Etelä-Savon, Itä- ja Pirkka-Hämeen sekä Etelä- ja Keski-Pohjanmaan piirimetsälautakuntien alueiden pohjois- ja itärajojen etelä- ja länsipuolella 46 % ja kuusen kuutiomäärästä 52 %.

Puuston kuutiomäärän alueellisen jakaantumisen muuttuminen on seurausta uudistamistoiminnan alueellisesti erilaisesta voimakkuudesta. Kuutiomäärän ja myös keskikuution pieneneminen on ollut selvintä siellä, missä uudistusalan taimisto- ja riukuvaiheen osuus on yli 30 % metsämaan pinta-alasta. Tällaisia alueita ovat koko Perä-Pohjola Inarin kuntaa ja Pelkosenniemen, Savukosken ja Sallan kuntien pohjoisosia lukuun ottamatta, Kainuu, Pohjois-Karjala ja Pohjois-Savon sekä Keski-Suomen pohjoispuoliskot. Suurimmillaan uudistusalan, taimisto- ja riukuvaiheen metsiköiden osuus on 45—50 % edellä mainituilla alueilla siellä, missä on runsaasti valtion ja yhtiöiden metsiä. Maan etelä-, lounais- ja länsiosissa on taas runsaasti alueita, joissa edellä mainittujen kehitysluokkien osuus on 20—25 %, mikä merkitsee sitä, että kaikkia kestäviä päätehakkuumahdollisuuksia ei ole käytetty hyväksi.

Kun otetaan huomioon metsämaan pinta-alan suurentuminen aikaisempaan kasvullisen metsämaan alaan verrattuna ja että lisäys on keskimääräistä vähäpuustoisempia alueita, niin keskikuution suureneminen tai säilyminen ennallaan III inventoinnin ajankohdan jälkeen merkitsee Etelä- ja Keski-Pohjanmaata lukuun ottamatta päätehakkuumahdollisuuksien vajaata hyväksi käyttöä. Pohjanmaalla on aikaisempi vajaapuustoisuus parantunut merkittävästi.

Voimakas uudistuminen ja metsämaan edellä todettu lisääntyminen huomioon ottaen voidaan päätellä, että kasvatettavien metsiköiden keskikuutio on yleensä lisääntynyt. Syynä tähän ei ole ollut niinkään metsiköiden tiheyden lisääntyminen, jota sitäkin on tapahtunut varsinaisilla hakkuusäästöalueilla, vaan kasvatettavien metsiköiden vanheneminen. Suuren kuutiotuotoksen kannalta metsät ovat liian harvoja. Pohjapinta-alalla mitattuna vajaatiheys on 10—20 %. Toisaalta pääasiassa alaharvennuksen luontoisilla hakkuilla käsitellyissä metsiköissä on puuston järeyden kehittyminen ollut koneellistuvan korjuun kustannuskehitystä ajatellen erittäin edullinen. Harvahkossa metsikössä kasvatetun järeän puusadon hakkuutähdeosuus on pienempi ja saanto jalostuksessa parempi kuin pieniläpimittaisista rungoista koostuvassa puusadossa. Näistä syistä viime aikoina vallinnut metsiköiden

kasvatustapa ei ole ollut niin epäedullinen kuin mitä pelkästään kuutiotuotoksen tarkasteluun perustuneessa arvostelussa on esitetty.

Puuston järeys on lisääntynyt koko tarkastelun kohteena olleen 50-vuotisen jakson aikana lukuun ottamatta sahateollisuuden valtakautta 1920- ja 1930-luvulla. Tällöin sahatukin osuus teollisuuspuusta oli 60—70 %, kun se nykyisin on noin 40 %. Vuosina 1940—70 yli 20 cm rinnankorkeudelta olevien puiden suhteellinen osuus puuston kuutiomäärässä on lisääntynyt yli prosenttiyksikön vuotta kohti ja siten, että lisääntyminen oli voimakkainta 1950-luvulla. Sanottu osuus oli 1960-luvun lopulla 56 %. Puuston järeytyminen jatkuu ainakin 1970-luvun aikana, joskin hidastuen.

Kokonaisuutena tukkipuusto on suurempi kuin koskaan aikaisemmin kuluvalla vuosisadalla. Se keskittyy kuitenkin maan eteläpuoliskoon ja kuusen osuus kasvaa siinä koko ajan. Pohjoisimmassa osassa tukkipuusto ja ennen muuta sen järein osa on pienentynyt. Sahaustuloksen kannalta on kuitenkin syytä korostaa sitä, että vanha, paljon sydänpuuta sisältävä mäntytukki on luonnonmetsien vähetessä myös vähentynyt voimakkaasti.

Tukkipuiden määrittely on vaihdellut eri inventoinneissa, joten arviot eivät muodosta täsmällistä aikasarjaa. Suuruusluokkakäsityksen antamiseksi voidaan todeta, että Suomen nykyisellä pinta-alalla vähintään 20 cm rinnankorkeusläpimitaltaan olevien tukkirunkojen lukumäärän arvio, joka 1960-luvun lopulla oli 1 422 milj. kpl, suureni vuosina 1937—67 noin 37 %, mäntytukkien 19 %, kuusitukkien 79 % ja lehtipuutukkien 29 %. Lehtipuutukkien lukumäärä oli suurimmillaan 1950-luvun alussa ja sen pieneneminen on todennäköisesti kiihtyvää.

Puuston kasvun arvio, joka 1960-luvun lopussa oli 47.6 milj. m^3 kuoretonta puuta vuotta kohti, on inventointien tuloksissa suurentunut. Todellista suurentumista oli 1940-luvulla ja 1950-luvun alussa. Muulta osalta arvioiden suureneminen on johtunut kasvunarviomismenetelmän muutoksesta III ja V inventoinnissa. III inventoinnissa läpimitan kasvun kairausjakso muuttui 10 vuodesta 5 vuodeksi ja V inventoinnissa otettiin likimääräisesti huomioon mittausjakson aikana metsistä poistuneiden puiden kasvu. 1950- ja 1960-luvulla tapahtuneiden uudistusalan ja taimistojen lisääntymisen, kuutiomäärällä punnitun puuston keski-iän suurenemisen ja puuston järeytymisen ja kuutiomäärän pienenemisen vuoksi kasvun olisi pitänyt pienetä. Sen säilyminen likimain muuttumattomana on ollut mahdollista vain metsänparannuksen, lähinnä ojituksen kasvua lisänneen vaikutuksen johdosta. Ilman ojitusta nykyinen puun käyttö olisikin selvästi kestävyyden ylittävää.

Maan eteläpuoliskossa kasvun suureneminen on ollut todellista, sillä V inventoinnin arvio on 7.6 % suurempi kuin III inventoinnin arvio. Arvioimismenetelmän muutoksen aiheuttama lisäys on 3—4 %. Pohjoispuoliskossa kasvun arvio on pienentynyt 10.0 %, todellisena noin 13 %, mikä johtuu puuston kuutiomäärän pienenemisestä.

Puulajien osuudet kasvusta kehittyvät siten, että männyn osuus pienenee niin kauan, kunnes uusien männiköiden kasvu alkaa merkittävästi lisääntyä, kuusen osuus suurenee ja lehtipuiden pienenee selvästi. Maan pohjoispuoliskossa männyn osuus on suureneva seurauksena puulajisuhteiden kehittämisestä. Kasvun osuuden perusteella kuusi on jo valtapuu koko maassa ja erityisesti eteläpuoliskossa. Pohjoispuoliskossa männyn valtapuuasema voimistuu.

Suunnitteen arvio on 49.8 milj. m^3 kuoretonta puuta vuotta kohti. 1960-luvun alun tilanteeseen verrattuna suunnitteen arvio on suurentunut maan eteläpuoliskossa, pienentynyt selvästi pohjoispuoliskossa ja myös hieman koko maassa. Syynä pienentyneeseen arvioon on pohjoispuoliskon tilanteen kehittyminen epäedullisemmaksi kuin aikaisemmin arvioitiin. Puun korjuu ei ole pohjoisessa kohdistunut ensisijaisesti vanhimpiin metsikköihin, vaan parhaiden kasvu- ja menekkialueiden uudistuskypsyyden saavuttaneisiin metsikköihin. Puulajin muutokseen tähtäävässä uudistamisessa on koettu epäonnistumisia.

Koko puuston tehokasta hyväksikäyttöä edellyttävissä laskelmissa ja nykyiseen metsänparannukseen perustuen suurin kestävä suunnite on saatu noin 52 milj. m^3:ksi. Toisaalta kaikki metsät eivät ole tehokkaassa käytössä ja uudistaminen ei kohdistu kaikkialla ensisijaisesti niihin metsikköihin, joihin sen puuston kehittämisen kannalta tulisi kohdistua. Metsänviljelyssä, taimiston hoidossa ja metsäojien kunnossa pidossa on niin paljon heikkouksia, että tähänastisen tapahtumisen jatkuessa 49.8 milj. m^3:kin suuruinen suunnite voi osoittautua todellisia kestäviä korjuumahdollisuuksia suuremmaksi. Sellaiseksi se osoittautuu ainakin siinä tapauksessa, jos yleiseen mielipiteeseen vakiintuu käsitys, että suuria osia kasvatettua puusatoa on seisotettava osana maisemaa ja elinympäristöä. Toisaalta paranevalla metsänhoidolla, lisääntyvällä perusparannuksena suoritettavalla metsänviljelyllä ja ennen muuta lannoituksella puun tuotantoa ja suunnitetta voitaisiin olennaisesti suurentaa jo 1970-luvulla, mutta sen saavuttamiseksi on metsäpolitiikan tehostuttava nykyisestään.

Suunnite perustuu yhä periaatteelle, että nykyistä vanhenevaa ja suurelta osalta huonolaatuista sekä vähäarvoista lehtipuustoa vähennetään joskaan ei suhteellisesti yhtä voimakkaasti kuin 1960-luvulla on tapahtunut. Mäntyä tulisi säästää sen kasvuun nähden suhteellisesti enemmän kuin kuusta, jota kasvaa erityisesti maan pohjoispuoliskossa sille epäedullisilla kasvupaikoilla.

Järeän puun ja tukin osuus on suunnitteessa suurentunut suhteessa niiden osuuden suurentumiseen puuston kuutiomäärässä.

Puutaseen osalta voidaan todeta, että sen osien arviot muodostavat verraten luotettavan kokonaisuuden, varsinkin maan eteläpuoliskon osalta. Puulajeittaisissa perustiedoissa ja maan pohjoispuoliskon tietojen osalla on

epävarmuutta, joka tulisi voida poistaa tarkentamalla arvioita mittausjakson aikana poistuneiden puiden kasvun osalta ja mahdollisesti myös puun käyttötutkimuksen poistuman arvioissa. Maan pohjoispuoliskossa olisi saatava aikaan hukkapuuta ja erityisesti luonnonpoistumaa koskevia lisätutkimuksia.

Jos V inventoinnin tulosten mukainen 49.8 milj. m^3:n suuruinen suunnite oletetaan realistiseksi, voidaan maan eteläpuoliskossa saavutettua poistuman tasoa 37 milj. m^3 vuotta kohti suurentaa noin 2 milj. m^3:llä. Tähän päästäisiin suurentamalla kuusen poistumaa noin 3 milj. m^3, pienentämällä lehtipuun poistumaa 1 milj. m^3 ja säilyttämällä männyn poistuma ennallaan. Maan pohjoispuoliskossa tulisi poistuman pienetä noin 1.5 milj. m^3 ja tämän pienenemisen tulisi kohdistua mäntyyn. Jotta pohjoispuoliskossa lievennettäisiin tulevaisuuteen kasautuvia vaikeuksia, olisi puun korjuuta siirrettävä vähintään sanottu 1.5 milj. m^3 eteläpuoliskoon.

Edellä esitetyt päätelmät koskevat 1960-luvun lopun tilannetta. Tehtyjen arvioiden mukaan (esim. L i n n a m i e s 1971) teollisuuden tuotantotehon lisääntyminen lisää 1970-luvun puolivälin tienoilla kotimaista pyöreän puun tarvetta 4—5 milj. m^3. Vaikka muu puun käyttö pieneneekin samanaikaisesti 0.3—0.5 milj. m^3 vuodessa, muodostuu teollisuuden puun tarve niin suureksi, että sen tyydyttäminen johtaa joko kestävyyden ylittämiseen tai puun tuotannon panoksia on lisättävä olennaisesti nykyisestään.

Puun käytön rakenteessa tapahtunut paperipuun tarpeen kasvu ja puuston järeytyminen on johtanut tilanteeseen, jossa havutukin mitta- ja laatuvaatimukset täyttävää puuta, ennen muuta kuusta, joudutaan käyttämään hiokkeen ja selluloosan raaka-aineena 3—4 milj. m^3 vuodessa. Toinen olennainen piirre on se, että lehtipuutukin korjuumahdollisuuksien pieneneminen johtaa joko vanerin tuotannon pienenemiseen tai koivutukkia on korvattava havupuulla, pääasiassa kuusella. Suunnitteen lehtipuutukkiosuuden perusteella tarvittava raakapuun rakennemuutos olisi 1970-luvulla suuruusluokaltaan 0.5 milj. m^3 edellyttäen, että vanerin tuotanto on samansuuruinen kuin v. 1970.

Metsien metsänhoidollista tilaa kuvaavien tietojen mukaan kehityskelpoisten metsiköiden laatu on parantunut oleellisesti 1950- ja 1960-luvulla. Puustoa heikentävä harsinta on vähentynyt selvästi. Vajaatuottoisten metsiköiden osuuden suurena säilyminen osoittaa taas, että V inventoinnin suorittamisajankohtaan mennessä ei oltu onnistuttu ratkaisemaan vajaatuottoisten metsiköiden perusparannusuudistamista. Toisaalta on kuitenkin syytä todeta, että huonolaatuisin puu tuli säännöllisen kysynnän piiriin vasta 1960-luvun loppupuoliskolla. Maatalouden metsittyneistä laitumista ja myös pelloista on todennäköisesti huomattava osa vajaatuottoisia metsiköitä. Ojitusalueiden puutteellinen kunto ja viljelytaimistojen harvuus ja hoitoa tarvitsevien taimistojen määrä osoittavat, että suoranaisia kustannuksia vaativia metsänhoito- ja parannustöitä ei tehdä riittävästi.

Maan ja metsän omistusta sekä sen kehittymistä koskevat inventointien tulokset on koottu kuvaan 20. Jos pidetään V inventoinnin tulosten mukaista pinta-alaa ja metsävarojen määrää vertauskohtana, niin omistussuhteiden suhteellisten muutosten perusteella saadaan oheinen asetelma, joka osoittaa suuruusluokka-arvioina, mistä omistussuhteiden muutoksessa on ollut kysymys.

Tunnus	Yksityinen	Osakeyhtiö	Valtio	Kunta, seurakunta, yhteisö
		Muutos vuosina 1920—70		
Maa, 1 000 ha	+3 055	—275	—3 360	+580
Metsämaa, 1 000 ha	+1 945	—112	—2 188	+355
Kuutiomäärä, milj. m³ kuorineen	+ 296	— 54	— 261	+ 19
Kasvu, milj. m³ kuoretta	+ 6.0	— 2.1	— 4.2	+ 0.3
Suunnite, milj. m³ kuoretta	+ 8.0	— 2.9	— 5.7	+ 0.6

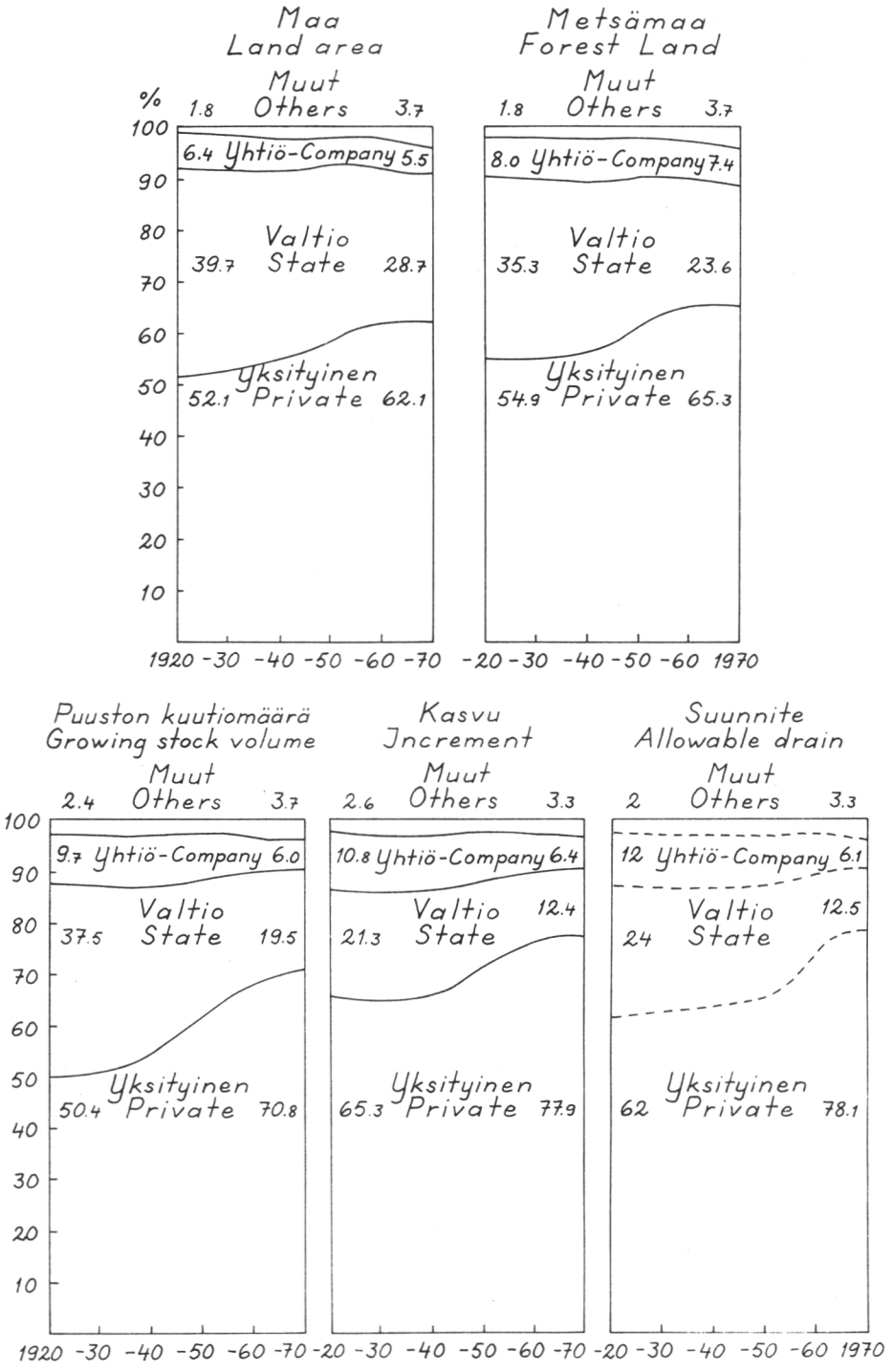
Pääsyynä omistussuhteiden muutokseen on ollut tilattoman ja muihin elinkeinoihin sijoittumattoman väestön asuttaminen ja uusien tilojen perustaminen sekä lisämaiden ottaminen pääasiassa valtion ja osakeyhtiöiden maista. Suurimmillaan asuttaminen oli II maailmansodan jälkeen, jolloin perustettiin myös menetettyjen alueiden väestölle uudet tilat.

Suhteellisesti raskaimmin asutus on muuttanut valtion metsätalouden toimintaedellytyksiä sen vuoksi, että valtion metsätalous menetti pääasiassa parhaita maita, joilla oli suurimmaksi osaksi päätehakkuukypsyyden saavuttanutta puustoa. Tästä syystä tulonsaantimahdollisuudet valtion metsistä ovat pienentyneet niin paljon, että ilman tapahtuneita muutoksia valtion metsien kantorahatulot olisivat vähintään kaksinkertaiset siihen noin 100 milj. markan määrään verrattuna, mitä ne olivat vuonna 1970.

Osakeyhtiöiden metsäomaisuus on pienentynyt asutuksen vuoksi suhteellisesti vähemmän kuin valtion metsät. Sen lisäksi yhtiöiden metsissä suoritetut voimakkaat päätehakkuut ovat pienentäneet puustoa niin paljon, että osakeyhtiöiden osuus lähitulevaisuuden hakkuumahdollisuuksista on pienentynyt suhteellisesti vielä enemmän kuin valtion metsissä.

Muista omistajista kunnat ja seurakunnat ovat ilmeisesti metsänostojen kautta säilyttäneet likimain aikaisemman suhteellisen asemansa, kun taas yhteisömetsät ovat yhteismetsien perustamisen ja säätiöiden metsänostojen kautta tulleet uudeksi, joskin sinänsä pieneksi metsänomistusmuodoksi.

Varsinaisten yksityismetsien osuus puun tuotannosta on 78 %, johon voidaan vielä lisätä yksityisten omistamat yhteismetsät. Koska hakkuutähde ja luonnonpoistuma keskittyy suurelta osalta valtion metsiin, on yksityisten osuus käyttöpuun tuotoksesta yli 80 %. Valtion osuus suunnitteesta on 12.5 % ja mikäli valtion pohjoisimpia metsiä jätetään korjuutoiminnan ulkopuolelle, pienenee osuus vielä tästäkin. Osakeyhtiöiden osuus on noin 6 % ja muiden omistajien runsaat 3 %.



Kuva 20. Maan ja metsän omistuksen kehittyminen vuosina 1920—70.
Fig. 20. Development of the land and forest ownership conditions in 1920—70.

Sikäli kuin metsien alueellisen sijainnin erilaisuuden vuoksi eri omistajien metsien hoidollista tilaa ja laatua voidaan verrata toisiinsa, niin parhaiten hoidettuja ovat yhtiöiden metsät ja sen jälkeen tulevat likimain samanlaisina valtion, kuntien, seurakuntien ja yhteisöjen metsät.

Ottamalla huomioon yksityismetsien sijainti parhailla menekkialueilla, niiden tila jää heikoimmaksi. Syynä tähän on pääasiassa yksityisen metsänomistajan muita vähäisempi alttius suorittaa pitkäaikaisesti vaikuttavia perusparannuksia, joihin ei ole myöskään puuston kunnostamisen osalta ohjattu julkisia varoja niin paljon kuin metsätalouden kansantaloudellinen merkitys ehkä edellyttäisi.

Yksityismetsien suuresta ja lisääntyneestä osuudesta on kuitenkin ollut metsä- ja puutaloudelle sekä puunjalostuksen varassa kehittyneelle kansantaloudelle korvaamatonta etua sikäli, että maa- ja karjataloutta pääelinkeinona harjoittavan väestön hajasijoitus metsäseudulle on tuonut työvoimaa, asuntoja ja kuljetusteitä myös metsä- ja puutaloudelle ilman, että näiden elinkeinojen on tarvinnut täydellä osuudellaan osallistua metsänhoidon, puun korjuun ja kuljetuksen kaikkiin kustannuksiin sellaisena, kuin ne esiintyvät alueilla, joilla ei ole haja-asutettua väestöä. Pientiloille asutetun väestön työn ja tulojen tarve on tähän asti turvannut metsätyövoiman ja runsaan puun tarjonnan yksityismetsistä. Ilman hajasijoitettua maatalousväestöä ja pientilavaltaista asutusta metsien käyttö ei olisi voinut saavuttaa läheskään samaa tehokkuutta, mikä on vallinnut 1950- ja 1960-luvulla. Niinpä viimeaikainen puun käyttö on vastannut maan eteläpuoliskossa pystypuuston suuruisen kuutiomäärän korjaamista kerran 22 vuodessa ja siitä huolimatta puuston kuutiomäärä on säilynyt ennallaan ja kasvu suurentunut. Vastaava suhdeluku pohjoispuoliskossa on ollut 34 v. ja koko maassa 24 v. Kun vielä otetaan huomioon hakkuutähteiden ja luonnonpoistuman suhteellisesti pieni määrä, niin vastaavaa tehokkuutta metsän käytössä ei kansainvälisten tilastojen mukaan ole saavutettu muualla Suomea vastaavissa luonnonoloissa.

LIITETAULUKOT — *ABBENDIX TABLES*

METSÄVARATIETOJA VUOSILTA 1964—70
FOREST RESOURCE DATA IN 1964—70

Taulukko 1. Metsätalouden maan luokat omistajittain maan etelä- ja pohjoispuoliskossa sekä koko maassa.
Table 1. Forestry land classes by ownership categories in southern and northern half of the country.

Maaluokka *Land class*	Alue *Area*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, Church*	Yhteisö *Corporation*	Yhteensä *Total*
		1 000 ha — %					
Metsämaa — *Forest land*	Eteläpuolisko — *Southern half*	8 759	1 109	707	260	109	10 944
		80.0	10.1	6.5	2.4	1.0	100.0
	Pohjoispuolisko — *Northern half* ..	3 442	279	3 703	90	235	7 749
		44.4	3.6	47.8	1.2	3.0	100.0
	Koko maa — *Whole country*	12 201	1 388	4 410	350	344	18 693
		65.3	7.4	23.6	1.9	1.8	100.0
Kitumaa — *Poorly productive forest land*	Eteläpuolisko — *Southern half*	716	94	99	21	14	944
		75.8	10.0	10.5	2.2	1.5	100.0
	Pohjoispuolisko — *Northern half* ..	995	51	1 601	15	67	2 729
		36.5	1.9	58.7	0.5	2.4	100.0
	Koko maa — *Whole country*	1 711	145	1 700	36	81	3 673
		46.6	3.9	46.3	1.0	2.2	100.0
Joutomaa — *Waste land*	Eteläpuolisko — *Southern half*	568	80	135	23	30	836
		67.9	9.6	16.1	2.8	3.6	100.0
	Pohjoispuolisko — *Northern half* ..	939	51	2 340	18	46	3 394
		27.7	1.5	68.9	0.5	1.4	100.0
	Koko maa — *Whole country*	1 507	131	2 475	41	76	4 230
		35.6	3.1	58.5	1.0	1.8	100.0
Muu metsätalouden maa *Other forestry land*	Eteläpuolisko — *Southern half*	30	6	4	2	1	43
		69.8	14.0	9.3	4.6	2.3	100.0
	Pohjoispuolisko — *Northern half* ..	12	3	11	1	1	28
		42.8	10.7	39.3	3.6	3.6	100.0
	Koko maa — *Whole country*	42	9	15	3	2	71
		59.2	12.7	21.1	4.2	2.8	100.0
Yhteensä metsätalouden maa *Total forestry land*	Eteläpuolisko — *Southern half*	10 073	1 289	945	306	154	12 767
		78.9	10.1	7.4	2.4	1.2	100.0
	Pohjoispuolisko — *Northern half* ..	5 388	384	7 655	124	349	13 900
		38.7	2.8	55.1	0.9	2.5	100.0
	Koko maa — *Whole country*	15 461	1 673	8 600	430	503	26 667
		58.0	6.3	32.2	1.6	1.9	100.0

		Omistajien prosenttiosuus *Percentage of each ownership category*					
Metsämaa — *Forest land*	Eteläpuolisko — *Southern half*	87.0	86.0	74.8	85.0	70.8	85.7
Kitumaa — *Poorly prod. forest land*		7.1	7.3	10.5	6.9	9.1	7.4
Joutomaa — *Waste land*		5.6	6.2	14.3	7.5	19.5	6.6
Muu metsätal. maa — *Other forestry land*		0.3	0.5	0.4	0.6	0.6	0.3
Yhteensä — *Total*		100.0	100.0	100.0	100.0	100.0	100.0
Metsämaa — *Forest land*	Pohjoispuolisko — *Northern half* ..	63.9	72.7	48.4	72.6	67.4	55.8
Kitumaa — *Poorly prod. forest land*		18.5	13.3	20.9	12.7	19.3	19.6
Joutomaa — *Waste land*		17.4	13.3	30.6	14.2	13.1	24.4
Muu metsätal. maa — *Other forestry land*		0.2	0.7	0.1	0.5	0.2	0.2
Yhteensä — *Total*		100.0	100.0	100.0	100.0	100.0	100.0
Metsämaa — *Forest land*	Koko maa — *Whole country*	78.9	83.0	51.3	81.4	68.4	70.1
Kitumaa — *Poorly prod. forest land*		11.1	8.7	19.7	8.4	16.1	13.8
Joutomaa — *Waste land*		9.7	7.8	28.8	9.5	15.1	15.8
Muu metsätal. maa — *Other forestry land*		0.3	0.5	0.2	0.7	0.4	0.3
Yhteensä — *Total*		100.0	100.0	100.0	100.0	100.0	100.0

Taulukko 2 a. Metsätalouden maan omistus osa-alueilla (Kuva 1).
Table 2 a. Ownership of forestry land by sub-areas (Fig. 1).

Omistaja *Owner*	Maaluokka — *Land class*					
	Metsämaa *Forest land*	Kitumaa *Poorly productive forest land*	Joutomaa *Waste land*	Muu metsätal. maa *Other forestry land*	Yhteensä *Total*	
	% pinta-alasta — % *of land area*					1 000 ha
	Alue 1 — *Area 1*					
Yksityinen — *Private*	87.7	7.0	4.9	0.4	100.0	3 195
Osakeyhtiö — *Company*	88.9	5.7	4.8	0.6	100.0	241
Valtio — *State*	78.0	7.7	13.9	0.4	100.0	225
Kunta, seurakunta — *Commune, church*	84.9	6.5	7.5	1.1	100.0	99
Yhteisö — *Corporation*	80.0	11.8	7.6	0.6	100.0	57
	Alue 2 — *Area 2*					
Yksityinen — *Private*	91.9	4.7	3.1	0.3	100.0	1 707
Osakeyhtiö — *Company*	91.3	5.2	2.9	0.6	100.0	204
Valtio — *State*	92.5	4.8	2.2	0.5	100.0	65
Kunta, seurakunta — *Commune, church*	90.4	3.8	4.8	1.0	100.0	51
Yhteisö — *Corporation*	97.6	1.5	0.7	0.2	100.0	10
	Alue 3 — *Area 3*					
Yksityinen — *Private*	88.6	6.0	5.2	0.2	100.0	870
Osakeyhtiö — *Company*	81.3	9.3	18.9	0.5	100.0	292
Valtio — *State*	73.3	12.7	13.7	0.3	100.0	334
Kunta, seurakunta — *Commune, church*	86.5	7.6	5.7	0.2	100.0	35
Yhteisö — *Corporation*	88.9	5.9	5.0	0.2	100.0	8
	Alue 4 — *Area 4*					
Yksityinen — *Private*	93.4	4.2	2.2	0.2	100.0	2 010
Osakeyhtiö — *Company*	86.8	7.2	5.5	0.5	100.0	494
Valtio — *State*	82.1	9.0	8.3	0.6	100.0	162
Kunta, seurakunta — *Commune, church*	95.5	2.2	2.1	0.2	100.0	49
Yhteisö — *Corporation*	82.1	2.6	15.2	0.1	100.0	27
	Alue 5 — *Area 5*					
Yksityinen — *Private*	76.8	12.0	10.9	0.3	100.0	2 193
Osakeyhtiö — *Company*	78.2	11.1	9.9	0.8	100.0	50
Valtio — *State*	61.6	14.0	24.0	0.4	100.0	148
Kunta, seurakunta — *Commune, church*	75.7	11.8	12.3	0.2	100.0	71
Yhteisö — *Corporation*	47.4	12.0	38.3	2.3	100.0	53
	Alue 6 — *Area 6*					
Yksityinen — *Private*	69.4	14.7	15.7	0.2	100.0	2 461
Osakeyhtiö — *Company*	72.4	13.0	14.0	0.6	100.0	336
Valtio — *State*	66.7	14.1	18.9	0.3	100.0	1 309
Kunta, seurakunta — *Commune, church*	72.8	13.6	13.2	0.4	100.0	81
Yhteisö — *Corporation*	61.2	18.1	20.5	0.2	100.0	57
	Alue 7 — *Area 7*					
Yksityinen — *Private*	59.3	21.6	18.9	0.2	100.0	2 927
Osakeyhtiö — *Company*	74.8	16.0	7.9	1.3	100.0	48
Valtio — *State*	44.6	22.3	33.0	0.1	100.0	6 346
Kunta, seurakunta — *Commune, church*	72.3	10.9	16.1	0.7	100.0	43
Yhteisö — *Corporation*	68.6	19.5	11.7	0.2	100.0	292

Taulukko 2 b. Metsätalouden maan omistus osa-alueilla (Kuva 1).
Table 2 b. Ownership of forestry land by sub-areas (Fig. 1).

Omistaja *Owner*	Maaluokka — *Land class*				
	Metsämaa *Forest land*	Kitumaa *Poorly prod. forest land*	Joutomaa *Waste land*	Muu metsätal. maa *Other forestry land*	Yhteensä *Total*
	% pinta-alasta — % *of land area*				
	Alue 1 — *Area 1*				
Yksityinen — *Private*	84.4	83.5	74.1	77.2	83.7
Osakeyhtiö — *Company*	6.4	5.1	5.5	8.7	6.3
Valtio — *State*	5.3	6.5	14.8	5.4	5.9
Kunta, seurakunta — *Commune, church*	2.5	2.4	3.5	6.6	2.6
Yhteisö — *Corporation*	1.4	2.5	2.1	2.1	1.5
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 2 — *Area 2*				
Yksityinen — *Private*	83.8	83.5	84.3	71.1	83.8
Osakeyhtiö — *Company*	10.0	11.1	9.4	17.0	10.0
Valtio — *State*	3.2	3.2	2.3	4.5	3.2
Kunta, seurakunta — *Commune, church*	2.5	2.0	3.9	7.1	2.5
Yhteisö — *Corporation*	0.5	0.2	0.1	0.3	0.5
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 3 — *Area 3*				
Yksityinen — *Private*	59.7	41.8	37.9	40.6	56.5
Osakeyhtiö — *Company*	18.4	21.7	21.8	34.0	19.0
Valtio — *State*	19.0	34.0	38.3	23.4	21.7
Kunta, seurakunta — *Commune, church*	2.3	2.1	1.7	1.6	2.3
Yhteisö — *Corporation*	0.6	0.4	0.3	0.4	0.5
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 4 — *Area 4*				
Yksityinen — *Private*	74.8	61.9	49.2	53.0	73.3
Osakeyhtiö — *Company*	17.1	26.1	30.2	32.5	18.0
Valtio — *State*	5.3	10.7	14.9	12.8	5.9
Kunta, seurakunta — *Commune, church*	1.9	0.8	1.1	1.3	1.8
Yhteisö — *Corporation*	0.9	0.5	4.6	0.4	1.0
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 5 — *Area 5*				
Yksityinen — *Private*	89.0	86.5	77.5	73.7	87.2
Osakeyhtiö — *Company*	2.1	1.8	1.6	4.5	2.0
Valtio — *State*	4.8	6.8	11.5	6.6	5.9
Kunta, seurakunta — *Commune, church*	2.8	2.8	2.8	1.6	2.8
Yhteisö — *Corporation*	1.3	2.1	6.6	13.6	2.1
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 6 — *Area 6*				
Yksityinen — *Private*	58.5	59.2	54.9	50.2	58.0
Osakeyhtiö — *Company*	8.3	7.1	6.7	17.1	7.9
Valtio — *State*	30.0	30.2	35.2	28.8	30.9
Kunta, seurakunta — *Commune, church*	2.0	1.8	1.5	2.7	1.9
Yhteisö — *Corporation*	1.2	1.7	1.7	1.2	1.3
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 7 — *Area 7*				
Yksityinen — *Private*	35.9	29.9	20.6	39.0	30.3
Osakeyhtiö — *Company*	0.7	0.4	0.1	4.4	0.5
Valtio — *State*	58.6	66.8	77.7	51.4	65.7
Kunta, seurakunta — *Commune, church*	0.6	0.2	0.3	2.0	0.5
Yhteisö — *Corporation*	4.2	2.7	1.3	3.2	3.0
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0

Taulukko 3. Metsätalouden maa omistajittain ja alaryhmittäin.
Table 3. Forestry land by ownership categories and sub-groups

Omistaja *Owner*	Kangas *Mineral soils*	Korpi *Spruce and dec. swamp*	Räme *Pine swamp*	Neva *Open swamp*	Yhteensä *Total*	Kangas *Mineral soils*	Turvemaa *Peatland*	Yhteensä *Total*
	% alasta — % *of area*					1 000 ha		
	Eteläpuolisko — *Southern half*							
Yksityinen — *Private*	70.9	10.1	16.4	2.6	100.0	7 142	2 931	10 073
Osakeyhtiö — *Company*	65.3	9.6	22.1	3.0	100.0	842	447	1 289
Valtio — *State*	55.1	7.6	30.2	7.1	100.0	520	425	945
Kunta, seurakunta — *Commune church*	71.9	8.1	16.8	3.2	100.0	220	86	306
Yhteisö — *Corporation*	55.1	10.0	23.6	11.3	100.0	85	69	154
Yhteensä — *Total*	69.0	9.8	18.1	3.1	100.0	8 809	3 958	12 767
	Pohjoispuolisko — *Northern half*							
Yksityinen — *Private*	48.0	10.8	31.1	10.1	100.0	2 565	2 823	5 388
Osakeyhtiö — *Company*	53.7	6.0	33.9	6.9	100.0	206	178	384
Valtio — *State*	65.4	5.1	15.8	13.7	100.0	5 006	2 649	7 655
Kunta, seurakunta — *Commune, church*	58.0	5.3	26.6	10.1	100.0	72	52	124
Yhteisö — *Corporation*	66.0	5.0	21.2	7.8	100.0	230	119	349
Yhteensä — *Total*	58.1	7.4	22.6	11.9	100.0	8 079	5 821	13 900
	Koko maa — *Whole country*							
Yksityinen — *Private*	62.8	10.4	21.5	5.3	100.0	9 707	5 754	15 461
Osakeyhtiö — *Company*	62.4	8.8	24.8	4.0	100.0	1 048	625	1 673
Valtio — *State*	64.2	5.4	17.4	13.0	100.0	5 526	3 074	8 600
Kunta, seurakunta — *Commune, church*	67.8	7.3	19.7	5.2	100.0	292	138	430
Yhteisö — *Corporation*	62.6	6.4	22.0	9.0	100.0	315	188	503
Yhteensä — *Total*	63.3	8.6	20.4	7.7	100.0	16 888	9 779	26 667

Taulukko 4. Metsätalouden maa omistajittain ja alaryhmittäin osa-alueilla (Kuva 1).
Table 4. Forestry land by ownership categories and sub-groups in sub-area (Fig. 1).

Alaryhmä *Sub-class*	Yksityinen *Private*	Osakeyhtiö *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*
	% alasta — % *of area*				
	Alue 1 — *Area 1*				
Kangas — *Mineral soils*	79.1	76.3	61.9	79.3	63.3
Korpi — *Spruce and dec. swamp*	9.4	8.3	8.2	7.4	12.2
Räme — *Pine swamp*	10.0	13.2	24.6	10.4	21.5
Neva — *Open swamp*	1.5	2.2	5.3	2.9	3.0
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 2 — *Area 2*				
Kangas — *Mineral soils*	79.2	78.4	77.0	72.8	78.9
Korpi — *Spruce and dec. swamp*	9.2	9.1	9.8	11.2	11.3
Räme — *Pine swamp*	9.9	11.0	12.1	13.8	9.1
Neva — *Open swamp*	1.7	1.5	1.1	2.2	0.7
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 3 — *Area 3*				
Kangas — *Mineral soils*	67.8	58.4	51.7	68.3	53.7
Korpi — *Spruce and dec. swamp*	10.7	8.2	7.6	8.5	16.5
Räme — *Pine swamp*	18.6	29.1	33.3	20.2	29.2
Neva — *Open swamp*	2.9	4.3	7.4	3.0	0.6
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 4 — *Area 4*				
Kangas — *Mineral soils*	72.8	59.9	53.4	81.5	61.9
Korpi — *Spruce and dec. swamp*	12.4	11.3	8.1	7.6	10.6
Räme — *Pine swamp*	13.4	25.7	32.9	9.0	13.9
Neva — *Open swamp*	1.4	3.1	5.6	1.9	13.6
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 5 — *Area 5*				
Kangas — *Mineral soils*	52.7	51.3	44.6	56.3	37.9
Korpi — *Spruce and dec. swamp*	9.7	10.6	5.1	7.2	6.1
Räme — *Pine swamp*	32.0	32.9	36.9	31.4	32.9
Neva — *Open swamp*	5.6	5.2	13.4	5.1	23.1
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 6 — *Area 6*				
Kangas — *Mineral soils*	44.9	50.5	52.5	55.3	47.4
Korpi — *Spruce and dec. swamp*	9.9	6.0	4.9	4.9	3.0
Räme — *Pine swamp*	36.9	36.2	31.9	31.2	39.2
Neva — *Open swamp*	8.3	7.3	10.7	8.6	10.4
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0
	Alue 7 — *Area 7*				
Kangas — *Mineral soils*	50.6	71.6	68.1	63.1	69.6
Korpi — *Spruce and dec. swamp*	11.7	5.8	5.2	6.0	5.4
Räme — *Pine swamp*	26.2	18.3	12.4	17.9	17.7
Neva — *Open swamp*	11.5	4.3	14.3	13.0	7.3
Yhteensä — *Total*	100.0	100.0	100.0	100.0	100.0

Taulukko 5. Metsämaan kankaiden jakaantuminen kasvupaikkatyyppeihin (s. 10) omistajittain (Ilman luonnonsuojelualueita).

Table 5. Forest land mineral soils by site types (p. 123) and ownership categories (Without nature conservation areas).

Omistaja *Owner*	Kasvupaikkatyyppi — *Site type* 1	2	3	4	5	6	Yhteensä *Total*
	% alasta — % *of area*						
	Eteläpuolisko — *Southern half*						
Yksityinen — *Private*	1.1	26.3	40.6	29.7	2.3	0.0	100.0
Osakeyhtiö — *Company*	0.3	9.7	38.6	47.1	4.2	0.1	100.0
Valtio — *State*	0.2	4.4	31.4	53.7	9.9	0.4	100.0
Kunta, seurakunta — *Commune, church*	1.3	20.0	37.4	37.9	3.4	—	100.0
Yhteisö — *Corporation*	1.4	14.5	30.5	48.1	5.3	0.2	100.0
Yhteensä — *Total*	0.9	23.2	39.7	33.1	3.0	0.1	100.0
	Pohjoispuolisko — *Northern half*						
Yksityinen — *Private*	0.2	4.0	51.4	38.5	5.5	0.4	100.0
Osakeyhtiö — *Company*	0.1	2.4	45.8	49.0	2.5	0.2	100.0
Valtio — *State*	0.1	1.9	37.8	47.0	13.0	0.2	100.0
Kunta, seurakunta — *Commune, church*	0.9	2.4	39.2	45.8	10.4	1.3	100.0
Yhteisö — *Corporation*	0.1	2.6	43.9	46.7	6.7	—	100.0
Yhteensä — *Total*	0.1	2.7	42.6	44.2	10.1	0.3	100.0
	Koko maa — *Whole country*						
Yksityinen — *Private*	0.8	20.4	43.5	32.0	3.2	0.1	100.0
Osakeyhtiö — *Company*	0.2	8.3	40.0	47.5	3.9	0.1	100.0
Valtio — *State*	0.1	2.2	37.2	47.6	12.7	0.2	100.0
Kunta, seurakunta — *Commune, church*	1.2	15.7	37.8	39.9	5.1	0.3	100.0
Yhteisö — *Corporation*	0.5	5.8	40.3	47.1	6.3	0.0	100.0
Yhteensä — *Total*	0.5	13.4	41.1	38.4	6.4	0.2	100.0

Taulukko 6. Metsämaan kankaiden jakaantuminen kasvupaikkatyyppeihin (s. 10) omistajittain osa-alueilla (Kuva 1).

Table 6. Forest land mineral soils by site types (p. 123) and ownership categories in sub-areas (Fig. 1).

Omistaja *Owner*	Kasvupaikkatyyppi — *Site type* 1	2	3	4	5	6	Yhteensä *Total*
	% alasta — % *of area*						
	Alue 1 — *Area 1*						
Yksityinen — *Private*	1.3	25.8	39.5	31.3	2.1	0.0	100.0
Osakeyhtiö — *Company*	0.7	17.4	38.8	38.7	4.4		100.0
Valtio — *State*	0.4	6.1	32.9	46.1	14.5		100.0
Kunta, seurakunta — *Commune, church*	2.3	21.9	34.7	38.4	2.7		100.0
Yhteisö — *Corporation*	1.7	10.8	27.0	52.1	8.2	0.2	100.0
	Alue 2 — *Area 2*						
Yksityinen — *Private*	1.4	30.6	44.0	23.4	0.6		100.0
Osakeyhtiö — *Company*	0.3	9.5	43.0	46.4	0.8	0.0	100.0
Valtio — *State*	0.9	10.6	42.1	44.1	2.3		100.0
Kunta, seurakunta — *Commune, church*	0.6	19.9	45.6	33.2	0.7		100.0
Yhteisö — *Corporation*	0.8	24.3	37.7	34.7	1.7	0.8	100.0
	Alue 3 — *Area 3*						
Yksityinen — *Private*	0.5	27.4	44.0	25.3	2.5	0.3	100.0
Osakeyhtiö — *Company*		5.1	38.4	50.0	6.2	0.3	100.0
Valtio — *State*		0.3	26.7	65.7	6.3	1.0	100.0
Kunta, seurakunta — *Commune, church*	0.2	15.2	38.8	39.5	6.3		100.0
Yhteisö — *Corporation*		3.7	51.7	44.6			100.0
	Alue 4 — *Area 4*						
Yksityinen — *Private*	1.2	35.0	40.8	22.0	1.0	0.0	100.0
Osakeyhtiö — *Company*	0.1	8.0	37.0	50.9	4.0		100.0
Valtio — *State*	0.2	4.2	35.1	51.7	8.8		100.0
Kunta, seurakunta — *Commune, church*	1.1	25.5	39.2	29.1	5.1		100.0
Yhteisö — *Corporation*	2.0	20.9	37.7	38.3	1.1		100.0
	Alue 5 — *Area 5*						
Yksityinen — *Private*	0.2	11.1	37.1	45.4	6.2		100.0
Osakeyhtiö — *Company*	0.4	5.2	30.1	50.0	14.3		100.0
Valtio — *State*	0.2	7.0	27.6	48.1	16.6	0.5	100.0
Kunta, seurakunta — *Commune, church*	1.0	13.7	32.2	49.5	3.6		100.0
Yhteisö — *Corporation*	1.0	13.2	24.3	55.5	6.0		100.0
	Alue 6 — *Area 6*						
Yksityinen — *Private*	0.2	5.7	50.8	35.9	6.5	0.9	100.0
Osakeyhtiö — *Company*	0.1	2.6	51.1	43.7	2.5		100.0
Valtio — *State*	0.1	1.9	56.2	34.7	7.1		100.0
Kunta, seurakunta — *Commune, church*	1.0	2.7	35.1	47.3	11.8	2.1	100.0
Yhteisö — *Corporation*	0.2	4.1	36.7	36.4	22.6		100.0
	Alue 7 — *Area 7*						
Yksityinen — *Private*	0.2	2.8	51.9	40.3	4.7	0.1	100.0
Osakeyhtiö — *Company*		1.7	19.9	75.0	2.4	1.0	100.0
Valtio — *State*	0.0	1.9	34.8	49.0	14.0	0.3	100.0
Kunta, seurakunta — *Commune, church*	0.7	1.9	46.1	43.3	8.0		100.0
Yhteisö — *Corporation*	0.1	2.4	44.9	48.1	4.5		100.0

Taulukko 7. Metsätalouden maan jakaantuminen veroluokkiin omistajittain (ilman luonnonsuojelualueita).

Table 7. Forestry land by tax classes and ownership categories (without nature conservation areas).

Omistaja *Owner*	Veroluokka — *Tax class*							Yhteensä *Total*
	IA	IB	II	III	IV	V	Joutomaa *Waste l.*	
	% alasta — *% of area*							
	Eteläpuolisko — *Southern half*							
Yksityinen — *Private*	15.1	24.2	23.3	16.7	7.6	4.8	8.3	100.0
Osakeyhtiö — *Company*	5.0	18.8	32.6	19.5	10.0	5.5	8.6	100.0
Valtio — *State*	2.0	12.4	28.7	20.4	11.7	6.9	17.9	100.0
Kunta, seurakunta — *Commune, church*	11.3	22.7	26.0	18.8	6.9	4.9	9.4	100.0
Yhteisö — *Corporation*	5.8	13.5	23.8	18.2	10.0	5.1	23.6	100.0
Yhteensä — *Total*	12.9	22.6	24.7	17.3	8.2	5.0	9.3	100.0
	Pohjoispuolisko — *Northern half*							
Yksityinen — *Private*	1.4	16.0	22.5	14.5	8.2	12.4	25.0	100.0
Osakeyhtiö — *Company*	0.9	16.7	28.5	13.7	10.2	8.0	22.0	100.0
Valtio — *State*	0.4	10.0	19.0	13.5	5.4	11.6	40.1	100.0
Kunta, seurakunta — *Commune, church*	1.5	17.0	26.6	18.6	8.5	8.2	19.6	100.0
Yhteisö — *Corporation*	0.8	15.3	28.2	16.6	5.7	12.8	20.6	100.0
Yhteensä — *Total*	0.8	12.7	21.0	14.0	6.7	11.8	33.0	100.0
	Koko maa — *Whole country*							
Yksityinen — *Private*	10.3	21.3	23.0	15.9	7.8	7.5	14.2	100.0
Osakeyhtiö — *Company*	4.0	18.3	31.7	18.1	10.1	6.1	11.7	100.0
Valtio — *State*	0.6	10.2	20.1	14.2	6.2	11.1	37.6	100.0
Kunta, seurakunta — *Commune, church*	8.5	21.1	26.3	18.5	7.3	5.9	12.4	100.0
Yhteisö — *Corporation*	2.4	14.8	26.8	17.2	7.0	10.4	21.4	100.0
Yhteensä — *Total*	6.7	17.5	22.8	15.6	7.4	8.5	21.5	100.0

Taulukko 8. Metsätalouden maan jakaantuminen veroluokkiin omistajittain osa-alueilla (Kuva 1).

Table 8. Forest land by tax classes and ownership categories in sub-areas (Fig. 1).

Omistaja *Owner*	Veroluokka — *Tax class*							Yhteensä *Total*
	IA	IB	II	III	IV	V	Joutomaa *Waste l.*	
	% alasta — *% of area*							
	Alue 1 — *Area 1*							
Yksityinen — *Private*	15.0	24.6	25.2	16.9	6.1	4.4	7.8	100.0
Osakeyhtiö — *Company*	10.0	22.6	30.9	20.0	5.9	3.6	7.0	100.0
Valtio — *State*	3.1	16.5	26.1	22.1	10.5	4.2	17.5	100.0
Kunta, seurakunta — *Commune, church*	13.3	22.7	26.2	17.8	5.3	5.0	9.7	100.0
Yhteisö — *Corporation*	6.3	12.8	27.7	24.0	9.4	6.8	13.0	100.0
	Alue 2 — *Area 2*							
Yksityinen — *Private*	20.7	31.3	23.3	12.3	4.5	3.5	4.4	100.0
Osakeyhtiö — *Company*	5.9	26.6	36.2	15.8	5.9	5.1	4.5	100.0
Valtio — *State*	6.8	21.8	31.3	23.9	9.2	4.0	3.0	100.0
Kunta, seurakunta — *Commune, church*	11.5	32.2	26.8	16.1	4.6	3.1	5.7	100.0
Yhteisö — *Corporation*	16.4	30.2	24.5	16.6	9.5	2.1	0.7	100.0
	Alue 3 — *Area 3*							
Yksityinen — *Private*	15.0	28.4	21.8	14.9	8.2	4.8	6.9	100.0
Osakeyhtiö — *Company*	2.3	17.0	32.2	15.7	14.4	7.1	11.3	100.0
Valtio — *State*	0.1	8.0	35.0	17.2	12.9	9.4	17.4	100.0
Kunta, seurakunta — *Commune, church*	9.9	19.1	31.3	18.5	7.8	6.0	7.4	100.0
Yhteisö — *Corporation*	1.1	20.3	32.0	13.1	22.6	1.6	9.3	100.0
	Alue 4 — *Area 4*							
Yksityinen — *Private*	22.5	27.1	21.4	15.8	6.5	3.3	3.4	100.0
Osakeyhtiö — *Company*	4.0	15.9	33.0	22.0	10.8	5.5	8.8	100.0
Valtio — *State*	1.9	13.6	28.2	23.7	14.2	6.2	12.2	100.0
Kunta, seurakunta — *Commune, church*	16.5	29.7	26.4	17.9	4.4	2.2	2.9	100.0
Yhteisö — *Corporation*	10.1	19.4	28.7	14.1	9.5	1.3	16.9	100.0
	Alue 5 — *Area 5*							
Yksityinen — *Private*	4.2	14.0	23.1	21.3	12.8	7.6	17.0	100.0
Osakeyhtiö — *Company*	1.8	8.5	23.5	29.1	13.6	7.1	16.4	100.0
Valtio — *State*	2.6	10.4	18.1	20.1	9.3	7.1	32.4	100.0
Kunta, seurakunta — *Commune, church*	5.6	12.6	22.0	22.8	12.0	7.6	17.4	100.0
Yhteisö — *Corporation*	1.3	7.0	15.7	14.6	9.5	6.3	45.6	100.0
	Alue 6 — *Area 6*							
Yksityinen — *Private*	1.9	15.9	21.8	15.5	12.0	9.7	23.2	100.0
Osakeyhtiö — *Company*	0.9	17.9	26.2	12.9	11.3	7.9	22.9	100.0
Valtio — *State*	0.5	16.8	25.1	13.8	9.3	9.5	25.0	100.0
Kunta, seurakunta — *Commune, church*	1.7	13.9	23.2	23.6	9.5	8.3	19.8	100.0
Yhteisö — *Corporation*	0.7	14.1	14.7	21.6	6.9	10.8	31.2	100.0
	Alue 7 — *Area 7*							
Yksityinen — *Private*	1.0	16.0	23.1	13.6	4.9	14.8	26.6	100.0
Osakeyhtiö — *Company*	0.1	8.8	44.9	19.5	2.5	8.9	15.3	100.0
Valtio — *State*	0.4	8.5	17.7	13.4	4.6	12.0	43.4	100.0
Kunta, seurakunta — *Commune, church*	0.9	22.8	33.0	9.1	6.8	8.1	19.3	100.0
Yhteisö — *Corporation*	0.8	15.5	30.9	15.7	5.4	13.2	18.5	100.0

Taulukko 9. Soiden ojitustilanne omistajittain (ilman luonnonsuojelualueita).
Table 9. Swamp drainage situation by ownership categories (without nature conservation areas).

Omistaja *Owner*	Luonnontilassa *In natural state*	Ojikko *Ditched*	Muuttuma *Transforming*	Turvekangas *Transformed*	Yhteensä *Total*
	% turvemaan alasta—% *of peatland area*				
	Eteläpuolisko — *Southern half*				
Yksityinen — *Private*	51.2	22.9	17.5	8.4	100.0
Osakeyhtiö — *Company*	51.1	27.4	15.4	6.1	100.0
Valtio — *State*	64.3	18.6	12.9	4.2	100.0
Kunta, seurakunta — *Commune, church*	45.8	24.4	22.1	7.7	100.0
Yhteisö — *Corporation*	57.5	25.3	13.0	4.2	100.0
Yhteensä — *Total*	52.6	23.0	16.8	7.6	100.0
	Pohjoispuolisko — *Northern half*				
Yksityinen — *Private*	71.8	20.5	5.8	1.9	100.0
Osakeyhtiö — *Company*	54.9	37.1	7.0	1.0	100.0
Valtio — *State*	87.8	9.9	2.0	0.3	100.0
Kunta, seurakunta — *Commune, church*	69.6	21.8	5.8	2.8	100.0
Yhteisö — *Corporation*	88.0	8.3	3.0	0.7	100.0
Yhteensä — *Total*	78.8	16.0	4.1	1.1	100.0
	Koko maa — *Whole country*				
Yksityinen — *Private*	61.4	21.7	11.7	5.2	100.0
Osakeyhtiö — *Company*	52.6	30.1	12.7	4.6	100.0
Valtio — *State*	84.5	11.2	3.5	0.8	100.0
Kunta, seurakunta — *Commune, church*	55.1	23.2	15.9	5.8	100.0
Yhteisö — *Corporation*	77.1	14.4	6.4	2.1	100.0
Yhteensä — *Total*	68.2	18.8	9.2	3.8	100.0

Taulukko 10. Soiden ojitustilanne omistajittain osa-alueilla (Kuva 1).
Table 10. Swamp drainage situation by ownership categories in sub-areas (Fig. 1).

Omistaja *Owner*	Luonnontilassa *In natural state*	Ojikko *Ditched*	Muuttuma *Transforming*	Turvekangas *Transformed*	Yhteensä *Total*
	% turvemaan alasta—% *of peatland area*				
	Alue 1 — *Area 1*				
Yksityinen — *Private*	48.9	17.4	21.8	11.9	100.0
Osakeyhtiö — *Company*	33.3	29.5	18.2	19.0	100.0
Valtio — *State*	50.5	22.6	16.9	10.0	100.0
Kunta, seurakunta — *Commune, church*	54.7	12.8	16.9	15.6	100.0
Yhteisö — *Corporation*	37.6	32.1	25.3	5.0	100.0
	Alue 2 — *Area 2*				
Yksityinen — *Private*	56.7	16.5	16.9	9.9	100.0
Osakeyhtiö — *Company*	38.5	31.8	17.3	12.4	100.0
Valtio — *State*	54.9	14.3	25.6	5.2	100.0
Kunta, seurakunta — *Commune, church*	35.7	24.0	35.9	4.4	100.0
Yhteisö — *Corporation*	73.3	11.8	7.6	7.3	100.0
	Alue 3 — *Area 3*				
Yksityinen — *Private*	56.9	20.9	14.3	7.9	100.0
Osakeyhtiö — *Company*	69.4	21.1	6.8	2.7	100.0
Valtio — *State*	76.2	15.9	7.0	0.9	100.0
Kunta, seurakunta — *Commune, church*	42.4	29.7	22.7	5.2	100.0
Yhteisö — *Corporation*	69.3	29.4	1.3		100.0
	Alue 4 — *Area 4*				
Yksityinen — *Private*	45.0	25.6	21.1	8.3	100.0
Osakeyhtiö — *Company*	46.3	30.1	20.1	3.5	100.0
Valtio — *State*	50.6	22.2	21.8	5.4	100.0
Kunta, seurakunta — *Commune, church*	40.3	29.6	22.9	7.2	100.0
Yhteisö — *Corporation*	53.7	25.4	16.4	4.5	100.0
	Alue 5 — *Area 5*				
Yksityinen — *Private*	52.6	27.6	13.9	5.9	100.0
Osakeyhtiö — *Company*	63.1	25.1	9.7	2.1	100.0
Valtio — *State*	69.7	17.3	9.9	3.1	100.0
Kunta, seurakunta — *Commune, church*	47.6	28.4	18.9	5.1	100.0
Yhteisö — *Corporation*	69.9	21.2	5.1	3.8	100.0
	Alue 6 — *Area 6*				
Yksityinen — *Private*	62.1	25.1	9.8	3.0	100.0
Osakeyhtiö — *Company*	51.4	40.1	7.4	1.1	100.0
Valtio — *State*	80.4	14.9	4.1	0.6	100.0
Kunta, seurakunta — *Commune, church*	67.9	22.2	6.2	3.7	100.0
Yhteisö — *Corporation*	66.4	21.3	9.6	2.7	100.0
	Alue 7 — *Area 7*				
Yksityinen — *Private*	80.8	16.1	2.2	0.9	100.0
Osakeyhtiö — *Company*	96.2	1.2	2.6		100.0
Valtio — *State*	90.2	8.3	1.3	0.2	100.0
Kunta, seurakunta — *Commune, church*	73.4	20.8	5.1	0.7	100.0
Yhteisö — *Corporation*	95.5	3.8	0.7		100.0

Taulukko 11. Puulajien vallitsevuus metsämaalla omistajittain (ilman luonnonsuojelualueita).

Table 11. Dominance of tree species on forest land by ownership categories (without nature conservation areas).

Omistaja *Owner*	Puuton *Treeless*	Vallitseva puulaji *Dominant tree species*			Yhteensä *Total*
		Mänty *Pine*	Kuusi *Spruce*	Lehtipuut *Deciduous sp.*	
	% alasta — % *of area*				
	Eteläpuolisko — *Southern half*				
Yksityinen — *Private*	3.6	44.5	41.1	10.8	100.0
Osakeyhtiö — *Company*	5.2	59.7	31.6	3.5	100.0
Valtio — *State*	4.5	66.0	26.2	3.3	100.0
Kunta, seurakunta — *Commune, church*	3.4	54.4	35.1	7.1	100.0
Yhteisö — *Corporation*	5.3	52.8	32.9	9.0	100.0
Yhteensä — *Total*	4.0	47.5	38.9	9.6	100.0
	Pohjoispuolisko — *Northern half*				
Yksityinen — *Private*	4.7	62.8	24.6	7.9	100.0
Osakeyhtiö — *Company*	6.5	73.8	16.3	3.4	100.0
Valtio — *State*	5.1	69.0	20.5	5.4	100.0
Kunta, seurakunta — *Commune, church*	5.1	78.7	13.0	3.2	100.0
Yhteisö — *Corporation*	1.6	72.6	23.0	2.8	100.0
Yhteensä — *Total*	4.9	66.7	22.1	6.3	100.0
	Koko maa — *Whole country*				
Yksityinen — *Private*	3.9	49.7	36.4	10.0	100.0
Osakeyhtiö — *Company*	5.5	62.5	28.5	3.5	100.0
Valtio — *State*	5.0	68.5	21.4	5.1	100.0
Kunta, seurakunta — *Commune, church*	3.7	60.9	29.4	6.0	100.0
Yhteisö — *Corporation*	2.9	66.3	26.2	4.6	100.0
Yhteensä — *Total*	4.3	55.5	32.0	8.2	100.0

Taulukko 12. Puulajien vallitsevuus metsämaalla omistajittain osa-alueilla (Kuva 1).
Table 12. Dominance of tree species on forest land by ownership categories in sub-areas (Fig. 1).

Omistaja *Owner*	Puuton *Treeless*	Vallitseva puulaji *Dominant tree species*			Yhteensä *Total*
		Mänty *Pine*	Kuusi *Spruce*	Lehtipuut *Deciduous sp.*	
	% alasta — % *of area*				
	Alue 1 — *Area 1*				
Yksityinen — *Private*	3.0	40.5	48.9	7.6	100.0
Osakeyhtiö — *Company*	3.7	46.6	45.6	4.1	100.0
Valtio — *State*	4.2	60.7	32.3	2.8	100.0
Kunta, seurakunta — *Commune, church* ..	2.1	53.8	37.9	6.2	100.0
Yhteisö — *Corporation*					
	Alue 2 — *Area 2*				
Yksityinen — *Private*	3.0	46.1	33.8	17.1	100.0
Osakeyhtiö — *Company*	6.7	57.1	32.3	3.9	100.0
Valtio — *State*	2.2	52.3	41.5	4.0	100.0
Kunta, seurakunta — *Commune, church* ..	2.5	50.5	38.1	8.9	100.0
Yhteisö — *Corporation*	6.5	42.2	37.2	14.1	100.0
	Alue 3 — *Area 3*				
Yksityinen — *Private*	3.2	45.2	34.6	17.0	100.0
Osakeyhtiö — *Company*	5.6	68.2	22.9	3.3	100.0
Valtio — *State*	6.1	69.5	22.4	2.0	100.0
Kunta, seurakunta — *Commune, church* ..	2.7	52.1	37.8	7.4	100.0
Yhteisö — *Corporation*	17.0	44.7	34.0	4.3	100.0
	Alue 4 — *Area 4*				
Yksityinen — *Private*	4.2	37.0	48.5	10.3	100.0
Osakeyhtiö — *Company*	5.0	61.5	30.5	3.0	100.0
Valtio — *State*	4.6	68.1	22.8	4.5	100.0
Kunta, seurakunta — *Commune, church* ..	2.7	51.4	42.7	3.2	100.0
Yhteisö — *Corporation*	7.1	44.7	41.2	7.0	100.0
	Alue 5 — *Area 5*				
Yksityinen — *Private*	4.6	57.6	29.6	8.2	100.0
Osakeyhtiö — *Company*	4.8	71.9	18.5	4.8	100.0
Valtio — *State*	2.3	73.0	18.7	6.0	100.0
Kunta, seurakunta — *Commune, church* ..	7.1	62.9	19.6	10.4	100.0
Yhteisö — *Corporation*	6.4	64.2	13.8	15.6	100.0
	Alue 6 — *Area 6*				
Yksityinen — *Private*	4.0	65.8	21.7	8.5	100.0
Osakeyhtiö — *Company*	5.4	74.8	17.1	2.7	100.0
Valtio — *State*	5.1	68.3	24.6	2.0	100.0
Kunta, seurakunta — *Commune, church* ..	5.7	78.6	11.6	4.1	100.0
Yhteisö — *Corporation*	1.4	77.3	15.4	5.9	100.0
	Alue 7 — *Area 7*				
Yksityinen — *Private*	5.4	59.9	27.4	7.3	100.0
Osakeyhtiö — *Company*	13.4	67.1	10.7	8.8	100.0
Valtio — *State*	5.2	69.2	19.1	6.5	100.0
Kunta, seurakunta — *Commune, church* ..	3.9	79.0	15.5	1.6	100.0
Yhteisö — *Corporation*	1.7	71.8	24.3	2.2	100.0

Taulukko 13. Metsiköiden ikärakenne metsämaalla omistajittain (ilman luonnonsuojelualueita).

Table 13. Age structure of the tree stands on forest land by ownership categories (without nature conservation areas).

Omistaja *Owner*	Puuton *Treeless*	Ikäluokka, vuotta — *Age class, years*								Yhteensä *Total*
		10	30	50	70	90	110	130	150+	
	% alasta — % *of area*									
	Eteläpuolisko — *Southern half*									
Yksityinen — *Private*	3.6	10.7	12.4	18.5	30.8	15.8	5.9	1.7	0.6	100.0
Osakeyhtiö — *Company*	5.2	24.6	11.6	12.9	19.6	15.5	7.5	2.6	0.5	100.0
Valtio — *State*	4.5	22.4	12.5	11.5	11.5	12.4	10.5	7.4	7.3	100.0
Kunta, seurakunta — *Commune, church*	3.4	17.9	11.1	13.1	22.3	18.4	10.4	2.8	0.6	100.0
Yhteisö — *Corporation*	5.3	17.1	10.3	12.9	23.1	20.1	8.3	2.5	0.4	100.0
Yhteensä — *Total*	3.8	13.1	12.3	17.3	28.1	15.7	6.5	2.2	1.0	100.0
	Pohjoispuolisko — *Northern half*									
Yksityinen — *Private*	4.7	9.0	11.4	13.0	12.2	13.2	13.4	9.1	14.0	100.0
Osakeyhtiö — *Company*	6.5	25.1	13.1	7.8	9.2	14.2	15.3	6.3	2.5	100.0
Valtio — *State*	5.1	10.6	8.6	9.0	6.1	6.1	9.2	9.2	36.1	100.0
Kunta, seurakunta — *Commune, church*	5.1	16.5	16.0	8.4	9.3	18.4	12.4	8.5	5.4	100.0
Yhteisö — *Corporation*	1.6	6.2	5.6	8.8	7.8	9.3	5.7	5.0	50.0	100.0
Yhteensä — *Total*	4.9	10.4	10.0	10.8	9.0	9.8	11.2	8.9	25.0	100.0
	Koko maa — *Whole country*									
Yksityinen — *Private*	3.9	10.2	12.1	17.0	25.5	15.1	8.0	3.8	4.4	100.0
Osakeyhtiö — *Company*	5.5	24.7	11.9	11.9	17.5	15.2	9.1	3.3	0.9	100.0
Valtio — *State*	5.1	12.5	9.2	9.4	7.0	7.1	9.4	8.9	31.4	100.0
Kunta, seurakunta — *Commune, church*	3.7	17.4	12.3	12.0	18.8	18.6	10.9	4.3	2.0	100.0
Yhteisö — *Corporation*	2.9	9.9	7.0	10.2	12.5	12.8	6.4	4.3	34.0	100.0
Yhteensä — *Total*	4.3	12.0	11.3	14.6	20.2	13.3	8.4	5.0	10.9	100.0

Taulukko 14. Metsiköiden ikärakenne metsämaalla omistajittain osa-alueilla (Kuva 1).
Table 14. Age structure of the tree stands on forest land by ownership categories in sub-areas (Fig. 1).

Omistaja *Owner*	Puuton *Treeless*	Ikäluokka, vuotta — *Age class, years*								Yhteensä *Total*
		10	30	50	70	90	110	130	150+	
	% alasta — % *of area*									
					Alue 1 — *Area 1*					
Yksityinen — *Private*	3.0	10.1	13.4	17.3	32.2	16.8	5.1	1.5	0.6	100.0
Osakeyhtiö — *Company*	3.7	18.2	12.4	12.0	27.5	18.6	5.4	1.8	0.4	100.0
Valtio — *State*	4.2	19.6	11.6	15.1	16.4	15.8	10.1	3.7	3.5	100.0
Kunta, seurakunta — *Commune, church* / Yhteisö — *Corporation*	2.1	14.8	14.2	13.2	22.1	22.0	8.7	2.5	0.4	100.0
					Alue 2 — *Area 2*					
Yksityinen — *Private*	3.0	10.1	15.0	24.2	32.6	10.5	3.4	1.0	0.2	100.0
Osakeyhtiö — *Company*	6.7	24.7	13.4	11.5	23.3	13.4	5.7	1.3		100.0
Valtio — *State*	2.2	25.4	14.3	7.6	18.5	14.0	12.0	5.4	0.6	100.0
Kunta, seurakunta — *Commune, church*	2.5	21.2	11.8	14.3	23.1	16.8	9.2	1.1		100.0
Yhteisö — *Corporation*	6.5	12.6	7.5	11.8	19.6	29.4	7.6	2.5	2.5	100.0
					Alue 3 — *Area 3*					
Yksityinen — *Private*	3.2	11.9	13.0	18.4	30.4	13.9	6.7	1.8	0.7	100.0
Osakeyhtiö — *Company*	5.6	24.7	9.7	13.4	15.7	15.1	9.7	5.4	0.7	100.0
Valtio — *State*	6.1	20.7	11.6	9.3	5.6	7.7	10.8	13.1	15.1	100.0
Kunta, seurakunta — *Commune, church*	2.7	14.6	10.2	10.3	30.3	12.2	13.5	5.3	0.9	100.0
Yhteisö — *Corporation*	17.0	21.3	4.3	4.2	16.2	24.2	8.5	4.3		100.0
					Alue 4 — *Area 4*					
Yksityinen — *Private*	4.3	12.2	11.3	17.4	30.7	16.6	5.5	1.5	0.5	100.0
Osakeyhtiö — *Company*	5.0	27.6	11.1	13.4	16.2	15.2	8.5	2.2	0.8	100.0
Valtio — *State*	4.7	26.8	11.7	13.4	13.8	14.3	6.7	4.7	3.9	100.0
Kunta, seurakunta — *Commune, church*	2.8	16.0	6.3	12.6	24.6	23.7	11.7	1.7	0.6	100.0
Yhteisö — *Corporation*	7.3	26.1	4.8	12.1	27.8	14.7	4.8	2.4		100.0
					Alue 5 — *Area 5*					
Yksityinen — *Private*	4.6	10.2	9.4	16.5	27.0	19.2	9.4	2.7	1.0	100.0
Osakeyhtiö — *Company*	4.8	24.1	16.4	14.6	19.9	14.7	4.6	0.6	0.3	100.0
Valtio — *State*	2.3	23.8	16.9	10.7	9.6	14.4	14.7	4.3	3.3	100.0
Kunta, seurakunta — *Commune, church*	7.1	23.9	10.5	13.9	15.1	12.6	11.1	4.4	1.4	100.0
Yhteisö — *Corporation*	6.4	14.0	10.4	15.8	23.4	17.2	10.8	2.0		100.0
					Alue 6 — *Area 6*					
Yksityinen — *Private*	4.0	11.1	13.1	13.2	15.0	16.8	14.4	7.9	4.5	100.0
Osakeyhtiö — *Company*	5.4	27.9	12.0	7.4	8.7	15.1	15.1	6.6	1.8	100.0
Valtio — *State*	5.1	17.2	9.7	6.5	5.4	9.7	14.7	13.4	18.3	100.0
Kunta, seurakunta — *Commune, church*	5.7	15.9	13.9	6.8	11.7	18.3	15.8	7.5	4.4	100.0
Yhteisö — *Corporation*	1.4	12.7	23.7	17.5	10.3	16.6	8.0	3.9	5.9	100.0
					Alue 7 — *Area 7*					
Yksityinen — *Private*	5.4	7.0	9.6	12.9	9.3	9.6	12.4	10.4	23.4	100.0
Osakeyhtiö — *Company*	13.4	6.4	20.9	10.6	12.4	8.4	16.7	3.8	7.4	100.0
Valtio — *State*	5.2	8.5	8.2	9.8	6.4	5.0	7.4	7.8	41.7	100.0
Kunta, seurakunta — *Commune, church*	3.9	17.6	20.1	11.2	4.7	18.8	6.1	10.3	7.3	100.0
Yhteisö — *Corporation*	1.7	5.0	2.4	7.3	7.4	8.0	5.3	5.2	57.7	100.0

Taulukko 15. Metsämaan metsiköiden kehitysluokat omistajittain.
Table 15. Development classes of the stands on forest land by ownership categories.

Omistaja *Owner*	Kehitysluokka — *Development class*									Yhteensä *Total*
	1	2	3	4	5	6	7	8	9	
	% metsämaan alasta—% *of forest land*									
	Eteläpuolisko — *Southern half*									
Yksityinen — *Private*	5.4	7.2	10.9	24.2	19.8	10.7	6.7	15.1		100.0
Osakeyhtiö — *Company*	7.3	6.4	29.3	19.8	14.7	9.0	8.2	5.3		100.0
Valtio — *State*	5.7	9.1	26.3	17.8	9.9	14.4	6.8	9.2	0.8	100.0
Kunta, seurakunta — *Commune, church*	5.2	7.6	16.6	19.1	16.7	13.7	11.2	9.6	0.3	100.0
Yhteisö — *Corporation*	6.9	5.9	18.0	18.1	18.4	11.3	10.0	11.4	0.0	100.0
Yhteensä — *Total*	5.6	7.2	14.0	23.2	18.6	10.8	7.0	13.5	0.1	100.0
	Pohjoispuolisko — *Northern half*									
Yksityinen — *Private*	7.7	9.2	17.6	17.6	13.2	14.8	3.4	16.5		100.0
Osakeyhtiö — *Company*	12.1	7.6	35.7	11.5	12.9	10.5	2.6	7.1		100.0
Valtio — *State*	9.6	11.8	13.8	10.7	9.9	21.7	4.8	17.5	0.2	100.0
Kunta, seurakunta — *Commune, church*	10.5	4.4	25.8	14.7	14.6	18.2	6.6	5.2		100.0
Yhteisö — *Corporation*	3.3	6.0	12.2	12.5	15.6	32.1	3.6	14.7		100.0
Yhteensä — *Total*	8.7	10.2	16.4	13.9	11.7	18.5	4.1	16.4	0.1	100.0
	Koko maa — *Whole country*									
Yksityinen — *Private*	6.1	7.7	12.8	22.4	17.9	11.8	5.8	15.5		100.0
Osakeyhtiö — *Company*	8.3	6.7	30.5	18.2	14.4	9.3	7.0	5.6		100.0
Valtio — *State*	9.0	11.3	15.9	11.9	9.9	20.5	5.1	16.1	0.3	100.0
Kunta, seurakunta — *Commune, church*	6.6	6.8	18.9	18.0	16.2	14.8	10.0	8.5	0.2	100.0
Yhteisö — *Corporation*	4.5	6.0	14.1	14.2	16.5	25.4	5.7	13.6	0.0	100.0
Yhteensä — *Total*	6.9	8.4	15.0	19.4	15.7	14.0	5.8	14.7	0.1	100.0

1. Aukea uudistusala tai siemenpuusto — *Open area or seed tree stand.*
2. Taimisto tai riukuvaihe sekä ylispuita — *Seedling or sapling stand with standards.*
3. Taimisto tai riukuvaihe — *Seedling or sapling stand.*
4. Harvennusmetsikkö — *Thinning stand.*
5. Väljennysmetsikkö — *Accretion stand.*
6. Uudistuskypsä metsikkö — *Mature stand.*
7. Suojuspuumetsikkö — *Shelterwood stand.*
8. Vajaatuottoinen metsikkö — *Low-yielding stand.*
9. Luonnonsuojelualue — *Nature conservation area.*

Taulukko 16. Metsämaa ja puusto kehitysluokittain (edellinen taulukko) ja omistajittain osa-alueilla (Kuva 1).
Table 16. Forest land and growing stock by development classes (previous table) in sub-areas (Fig. 1).

Omistaja *Owner*	Tunnus *Characteristic*		Kehitysluokka — *Development class* 1	2	3	4	5	6	7	8	9	Yhteensä *Total*
			Alue 1 — *Area 1*									
	Pinta-ala — *Area*	%	4.6	7.8	8.2	23.5	20.4	11.6	9.0	14.7	0.0	100.0
Yksityinen — *Private*	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.4	9.9	4.1	16.7	19.7	19.1	10.7	11.4	21.8	14.0
	Keskikuutio — *Mean volume*	m³/ha	10.6	69.4	16.4	103.4	156.5	164.4	92.1	80.2	185.8	103.0
	Pinta-ala — *Area*	%	6.3	7.2	17.2	21.6	19.1	11.1	10.3	7.2		100.0
Osakeyhtiö—*Company*	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.4	7.5	2.1	15.0	17.7	18.0	9.9	10.0		11.2
	Keskikuutio — *Mean volume*	m³/ha	11.4	51.4	8.0	92.4	140.2	157.9	88.9	73.1		84.5
	Pinta-ala — *Area*	%	5.1	6.1	21.3	26.4	14.0	13.8	7.0	5.2	1.1	100.0
Valtio — *State*	Keskipohjapinta-ala — *Mean basal area*	m²/ha	0.2	6.1	1.7	13.8	19.0	20.7	8.8	14.4	22.0	11.4
	Keskikuutio — *Mean volume*	m³/ha	1.8	40.2	6.4	78.6	143.2	178.6	76.7	112.4	186.5	82.6
Kunta, seurakunta — *Commune, church*	Pinta-ala — *Area*	%	3.4	9.1	12.9	17.6	18.2	12.7	14.0	12.1		100.0
Yhteisö — *Corporation*	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.3	10.3	3.2	15.0	16.6	17.1	10.5	10.3		11.9
	Keskikuutio — *Mean volume*	m³/ha	11.6	73.6	11.6	88.2	131.9	150.4	95.3	71.8		89.2
			Alue 2 — *Area 2*									
	Pinta-ala — *Area*	%	4.7	8.1	8.4	21.4	22.6	10.2	6.5	18.1		100.0
Yksityinen — *Private*	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.6	10.1	4.4	17.7	19.5	19.3	10.7	12.1		14.3
	Keskikuutio — *Mean volume*	m³/ha	11.1	70.8	19.2	114.9	157.0	165.5	91.7	85.6		106.3
	Pinta-ala — *Area*	%	8.1	7.2	25.3	18.3	18.2	9.6	8.8	4.5		100.0
Osakeyhtiö—*Company*	Keskipohjapinta-ala — *Mean basal area*	m²/ha	0.7	7.8	2.2	15.0	16.9	17.2	8.8	10.3		9.9
	Keskikuutio — *Mean volume*	m³/ha	5.3	61.1	9.0	91.3	137.4	149.5	78.3	73.3		73.4
	Pinta-ala — *Area*	%	3.1	12.8	22.5	15.4	17.2	11.7	11.9	4.1	1.3	100.0
Valtio — *State*	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.5	6.3	2.1	15.7	19.4	19.6	13.1	11.4	28.0	11.8
	Keskikuutio — *Mean volume*	m³/ha	10.5	49.6	10.2	98.3	160.7	170.5	117.1	69.7	250.0	91.8
	Pinta-ala — *Area*	%	5.4	11.1	14.0	19.8	13.0	14.8	12.2	9.1	0.6	100.0
Kunta, seurakunta — *Commune, church*	Keskipohjapinta-ala — *Mean basal area*	m²/ha	2.2	6.5	1.5	15.4	19.3	20.2	8.8	8.2	24.0	11.5
	Keskikuutio — *Mean volume*	m³/ha	19.1	55.5	6.0	91.8	161.4	177.4	75.2	65.6	230.4	90.0
	Pinta-ala — *Area*	%	6.5	5.0	15.1	8.5	12.6	34.4	10.1	7.8		100.0
Yhteisö — *Corporation*	Keskipohjapinta-ala — *Mean basal area*	m²/ha		8.0	3.6	20.6	21.6	18.4	13.5	14.8		14.3
	Keskikuutio — *Mean volume*	m³/ha		63.9	13.7	122.2	178.8	155.7	120.6	84.6		110.5

Taulukko 16. (jatkoa) — *Table 16 (cont.)*

			Alue 3 — *Area 3*								
Yksityinen — *Private*	Pinta-ala — *Area*	%	5.1	8.9	12.4	22.3	19.7	6.8	5.4	19.4	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.4	9.6	2.6	17.5	20.3	18.9	8.6	12.6	13.3
	Keskikuutio — *Mean volume*	m³/ha	10.1	61.7	10.1	107.0	151.8	147.3	68.4	84.2	91.1
Osakeyhtiö—*Company*	Pinta-ala — *Area*	%	7.8	8.5	31.2	15.9	13.4	9.9	7.8	5.5	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.3	8.3	2.1	17.0	19.7	19.6	8.9	8.5	9.9
	Keskikuutio — *Mean volume*	m³/ha	10.1	57.3	8.5	101.7	153.1	158.2	76.0	48.6	68.8
Valtio — *State*	Pinta-ala — *Area*	%	7.4	9.3	27.2	10.0	6.5	17.8	5.7	15.1	1.0	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	0.9	5.0	1.6	14.4	17.7	22.9	9.0	18.3	16.6	11.1
	Keskikuutio — *Mean volume*	m³/ha	6.4	35.6	6.3	86.8	132.8	190.0	78.7	131.3	120.2	82.2
Kunta, seurakunta — *Commune, church*	Pinta-ala — *Area*	%	3.6	2.2	19.1	24.1	26.4	6.7	7.0	10.9	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	2.0	6.4	1.0	15.3	20.0	17.6	11.6	13.2	12.8
	Keskikuutio — *Mean volume*	m³/ha	18.6	46.2	3.9	95.7	145.8	129.9	92.7	91.0	89.1
Yhteisö — *Corporation*	Pinta-ala — *Area*	%	17.0		29.8	8.5	8.5		27.7	8.5	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha			0.9	21.0	23.0		9.5	11.0	7.6
	Keskikuutio — *Mean volume*	m³/ha			3.2	130.2	165.0		72.7	73.1	52.4
			Alue 4 — *Area 4*								
Yksityinen — *Private*	Pinta-ala — *Area*	%	5.6	6.7	13.8	25.5	20.1	9.6	5.8	12.9	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	0.8	9.1	2.7	16.0	19.4	18.7	10.9	11.6	12.9
	Keskikuutio — *Mean volume*	m³/ha	5.5	60.1	10.9	96.5	147.7	151.4	91.9	78.1	90.0
Osakeyhtiö—*Company*	Pinta-ala — *Area*	%	7.1	4.8	35.2	21.3	12.3	7.5	7.5	4.3	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	0.9	6.0	1.5	13.9	17.1	17.5	8.7	10.5	8.3
	Keskikuutio — *Mean volume*	m³/ha	7.3	39.9	5.6	77.2	132.6	146.5	75.7	61.6	56.5
Valtio — *State*	Pinta-ala — *Area*	%	5.5	9.3	32.7	20.5	10.4	11.3	4.5	5.8	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	0.8	5.1	1.9	12.9	19.9	18.9	9.4	13.1	9.3
	Keskikuutio — *Mean volume*	m³/ha	3.6	34.1	7.2	71.9	145.9	158.0	77.5	98.7	62.7
Kunta, seurakunta — *Commune, church*	Pinta-ala — *Area*	%	5.0	6.1	15.6	16.2	17.2	19.9	14.7	4.2	1.1	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	0.7	5.2	1.6	16.4	17.7	16.6	10.8	9.4	11.0	11.7
	Keskikuutio — *Mean volume*	m³/ha	6.4	40.0	6.8	107.9	144.3	140.0	93.3	73.1	88.0	91.7
Yhteisö — *Corporation*	Pinta-ala — *Area*	%	7.3	3.0	25.5	14.9	30.3	7.5	2.4	9.1	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha		9.6	1.2	13.0	17.6	16.1	13.0	9.9	10.3
	Keskikuutio — *Mean volume*	m³/ha		47.9	4.6	76.3	128.0	141.1	85.1	62.7	71.1
			Alue 5 — *Area 5*								
Yksityinen — *Private*	Pinta-ala — *Area*	%	7.5	4.9	13.9	27.5	16.0	12.1	4.7	13.4	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.3	6.8	3.1	15.1	18.0	17.9	9.2	10.7	12.0
	Keskikuutio — *Mean volume*	m³/ha	8.6	38.3	11.1	81.8	127.6	131.1	68.9	60.8	74.2
Osakeyhtiö—*Company*	Pinta-ala — *Area*	%	8.7	4.5	36.6	25.7	9.5	5.1	2.8	7.1	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.8	4.2	3.3	14.8	16.3	18.9	10.6	7.6	8.7
	Keskikuutio — *Mean volume*	m³/ha	13.1	27.8	11.3	74.0	110.8	126.1	88.1	47.7	49.3
Valtio — *State*	Pinta-ala — *Area*	%	4.6	11.1	26.9	19.7	5.7	12.5	9.3	9.6	0.6	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.6	5.3	2.4	13.4	20.7	15.0	9.6	8.9	33.0	8.9
	Keskikuutio — *Mean volume*	m³/ha	9.1	31.3	8.4	75.0	158.5	112.3	72.0	55.2	280.7	57.5
Kunta, seurakunta — *Commune, church*	Pinta-ala — *Area*	%	9.2	6.5	24.2	20.6	11.5	12.5	5.2	10.3	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.6	5.4	2.1	14.6	20.2	18.1	10.6	11.4	10.7
	Keskikuutio — *Mean volume*	m³/ha	7.7	36.9	7.3	83.6	138.0	148.5	77.3	75.4	68.7
Yhteisö — *Corporation*	Pinta-ala — *Area*	%	10.8	4.3	18.9	27.7	12.5	6.5	5.2	14.0	0.1	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	2.5	7.3	3.0	12.9	16.7	16.3	13.8	14.1	28.0	10.1
	Keskikuutio — *Mean volume*	m³/ha	13.4	34.6	11.7	69.0	109.3	100.4	96.3	83.6	109.2	61.9

			Alue 6 — *Area 6*								
Yksityinen — *Private*	Pinta-ala — *Area*	%	6.6	8.3	18.5	22.6	11.8	11.9	3.5	16.8	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.3	5.4	2.7	13.0	17.9	17.7	7.3	10.0	10.1
	Keskikuutio — *Mean volume*	m³/ha	8.0	29.9	9.7	63.4	112.9	117.9	51.2	53.4	57.3
Osakeyhtiö—*Company*	Pinta-ala — *Area*	%	12.0	8.2	34.9	12.9	12.1	10.6	3.0	6.3	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.3	2.3	1.4	11.9	16.7	18.1	7.9	7.6	6.8
	Keskikuutio — *Mean volume*	m³/ha	8.2	13.4	4.7	57.4	110.3	120.7	57.4	41.3	41.6
Valtio — *State*	Pinta-ala — *Area*	%	8.0	10.7	20.5	10.5	10.1	20.8	2.3	16.1	1.0 100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	0.8	4.2	1.3	14.2	20.4	21.1	7.4	14.2	18.9 11.3
	Keskikuutio — *Mean volume*	m³/ha	5.2	28.3	5.0	77.8	136.2	146.8	54.2	92.3	131.3 74.3
Kunta, seurakunta — *Commune, church*	Pinta-ala — *Area*	%	10.4	5.5	22.8	20.0	13.0	15.1	7.6	5.6	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	2.1	4.5	1.9	13.3	18.9	15.8	7.5	5.4	9.1
	Keskikuutio — *Mean volume*	m³/ha	10.6	24.5	6.6	64.5	115.4	103.2	48.5	24.2	52.5
Yhteisö — *Corporation*	Pinta-ala — *Area*	%	1.8	8.4	36.3	21.3	10.2	12.3	1.7	8.0	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	0.9	2.8	2.5	16.5	16.1	17.6	4.0	5.2	9.1
	Keskikuutio — *Mean volume*	m³/ha	2.0	16.4	8.1	74.1	97.0	115.4	31.6	29.6	47.2
			Alue 7 — *Area 7*								
Yksityinen — *Private*	Pinta-ala — *Area*	%	8.2	10.4	15.9	17.5	13.0	13.0	3.7	18.3	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.9	6.9	2.8	11.7	14.9	13.9	7.1	9.1	9.1
	Keskikuutio — *Mean volume*	m³/ha	8.7	35.7	10.6	55.5	85.8	85.6	45.8	47.8	48.5
Osakeyhtiö—*Company*	Pinta-ala — *Area*	%	20.0	7.6	30.3	13.3	7.7	2.9	0.5	17.7	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	2.5	3.8	2.8	9.6	13.0	10.0	10.0	7.8	5.5
	Keskikuutio — *Mean volume*	m³/ha	10.3	18.8	9.3	43.6	70.6	40.8	26.2	38.4	25.7
Valtio — *State*	Pinta-ala — *Area*	%	9.9	12.7	13.2	11.0	9.2	20.4	5.6	18.0	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	1.7	5.8	2.3	10.1	12.8	12.5	6.1	10.3	8.3
	Keskikuutio — *Mean volume*	m³/ha	9.0	32.7	9.0	50.4	79.0	80.5	38.4	59.9	48.4
Kunta, seurakunta — *Commune, church*	Pinta-ala — *Area*	%	4.3	4.5	39.0	19.1	15.7	5.2	6.5	5.7	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha		17.0	2.7	13.9	16.8	7.4	4.5	2.0	7.6
	Keskikuutio — *Mean volume*	m³/ha		74.1	8.6	64.1	91.4	49.5	17.5	6.2	37.3
Yhteisö — *Corporation*	Pinta-ala — *Area*	%	3.8	5.1	8.3	11.5	17.2	34.1	4.0	16.0	100.0
	Keskipohjapinta-ala — *Mean basal area*	m²/ha	2.5	9.4	2.3	12.8	15.7	14.1	6.9	11.7	11.8
	Keskikuutio — *Mean volume*	m³/ha	14.2	50.8	9.1	68.2	96.0	94.3	41.2	73.5	73.8

Taulukko 17. Puuston kokonaiskuutiomäärä kuorineen omistajittain osa-alueilla (Kuva 1).

Table 17. Volume of the total growing stock, including bark, by ownership categories in sub-areas (Fig. 1).

Puulaji *Tree species*	Yksityiset *Private*	Osakeyhtiöt *Company*	Valtio *State*	Kunta, seurakunta *Commune, church*	Yhteisö *Corporation*	Yhteensä *Total*	
	% kuutiomäärästä — % *of volume*						Milj. m³ *Mill. m³*
	Alue 1 — *Area 1*						
Mänty — *Pine*	84.6	5.4	5.6	4.4		100.0	123
Kuusi — *Spruce*	87.3	5.7	3.9	3.1		100.0	165
Lehtipuut — *Dec. spp.*	89.5	4.6	3.1	2.8		100.0	51
Yhteensä — *Total*	86.7	5.4	4.4	3.5		100.0	339
	Alue 2 — *Area 2*						
Mänty — *Pine*	85.7	8.4	3.4	2.1	0.4	100.0	83
Kuusi — *Spruce*	84.9	8.1	3.4	2.7	0.9	100.0	60
Lehtipuut — *Dec. spp.*	92.4	3.8	1.6	1.7	0.5	100.0	49
Yhteensä — *Total*	87.2	7.1	2.9	2.2	0.6	100.0	192
	Alue 3 — *Area 3*						
Mänty — *Pine*	55.9	18.8	22.7	2.5	0.1	100.0	49
Kuusi — *Spruce*	64.3	12.9	19.0	3.2	0.6	100.0	36
Lehtipuut — *Dec. spp.*	77.7	10.8	9.8	1.6	0.1	100.0	26
Yhteensä — *Total*	63.8	15.0	18.4	2.5	0.3	100.0	111
	Alue 4 — *Area 4*						
Mänty — *Pine*	74.4	15.8	6.2	2.8	0.8	100.0	71
Kuusi — *Spruce*	83.9	10.7	2.6	2.0	0.8	100.0	99
Lehtipuut — *Dec. spp.*	87.4	7.2	3.6	1.2	0.6	100.0	41
Yhteensä — *Total*	81.4	11.8	4.0	2.1	0.7	100.0	211
	Alue 5 — *Area 5*						
Mänty — *Pine*	88.6	2.0	5.2	3.0	1.2	100.0	64
Kuusi — *Spruce*	93.9	0.9	2.3	2.3	0.6	100.0	54
Lehtipuut — *Dec. spp.*	90.3	1.0	4.2	2.6	1.9	100.0	24
Yhteensä — *Total*	90.9	1.4	3.9	2.7	1.1	100.0	142
	Alue 6 — *Area 6*						
Mänty — *Pine*	54.9	6.1	35.7	2.2	1.1	100.0	96
Kuusi — *Spruce*	51.6	5.6	40.8	1.2	0.8	100.0	58
Lehtipuut — *Dec. spp.*	62.5	4.3	31.2	1.1	0.9	100.0	30
Yhteensä — *Total*	55.1	5.7	36.6	1.7	0.9	100.0	184
	Alue 7 — *Area 7*						
Mänty — *Pine*	29.7	0.4	62.5	0.6	6.8	100.0	150
Kuusi — *Spruce*	41.7	0.2	52.4	0.1	5.6	100.0	67
Lehtipuut — *Dec. spp.*	38.5	0.5	57.0	0.2	3.8	100.0	52
Yhteensä — *Total*	34.4	0.4	58.9	0.4	5.9	100.0	269

Taulukko 18. Suunnite puutavaralajeittain.
Table 18. Allowable cut by timber assortments.

Piirimetsälautakunta *Forestry Board District*	Mänty *Pine*	Kuusi *Spruce*	Lehtip. *Dec. sp.*	Yht. *Total*	Mänty *Pine*	Kuusi *Spruce*	Lehtip. *Dec. sp.*	Mänty *Pine*	Kuusi *Spruce*	Lehtip. *Dec. sp.*	Mänty *Pine*	Kuusi *Spruce*	Lehtip. *Dec. sp.*
	Milj. m³ kuorineen *Mill. m³ incl. bark*				Tukki, milj. j³ *Saw log, mill. cu.ft.*			Paperipuu — *Pulp wood*			Ohutpuu — *Small timber*		
								1 000 p-m³ — *1 000 m³ stacked measure*					
0. Ahvenanmaa	0.12	0.11	0.06	0.29	1.29	0.79	0.13	63	64	66	8	13	10
1. Helsinki	0.52	0.76	0.44	1.72	5.12	5.90	1.74	269	456	419	42	92	72
2. Lounais-Suomi	0.71	0.92	0.36	1.99	6.11	5.80	0.89	401	607	302	68	124	91
3. Satakunta	0.69	1.11	0.50	2.30	5.80	8.40	0.92	365	692	448	93	120	128
4. Uusimaa-Häme	0.56	1.68	0.60	2.84	7.52	16.57	2.56	188	847	538	31	159	108
5. Pohjois-Häme	0.87	1.96	0.62	3.45	10.04	18.52	2.65	366	965	529	70	265	140
6. Itä-Häme	0.74	1.38	1.00	3.12	9.32	13.63	5.18	284	679	910	41	148	150
7. Etelä-Savo	1.30	1.27	1.42	3.99	14.47	8.80	6.50	593	839	1 352	88	136	192
8. Etelä-Karjala	0.90	1.21	0.64	2.75	10.02	8.90	3.11	410	740	556	61	163	116
9. Itä-Savo	0.84	0.77	0.99	2.60	9.70	5.67	5.43	353	490	902	57	82	133
10. Pohjois-Karjala ...	1.54	1.76	1.35	4.65	17.14	11.09	4.94	684	1 162	1 285	104	238	263
11. Pohjois-Savo	1.09	2.34	1.75	5.18	12.81	18.67	7.47	432	1 404	1 642	74	221	288
12. Keski-Suomi	1.37	1.85	1.42	4.64	15.54	15.16	6.50	592	1 110	1 312	93	150	234
13. Etelä-Pohjanmaa ..	1.17	1.09	0.57	2.83	7.85	7.33	0.70	716	706	479	174	147	188
14. Vaasa	0.37	0.71	0.44	1.52	3.04	4.33	0.55	212	486	388	41	86	132
15. Keski-Pohjanmaa ..	0.63	0.47	0.58	1.68	3.44	2.27	0.52	401	332	447	111	82	217
Eteläpuolisko *Southern half*	13.42	19.39	12.74	45.55	139.21	151.83	49.79	6 329	11 579	11 575	1 156	2 226	2 462
16. Kainuu	1.62	1.34	0.51	3.47	18.69	7.77	0.30	636	876	490	135	202	120
17. Pohjois-Pohjanmaa	1.31	0.75	0.72	2.78	8.53	3.78	0.21	786	512	595	212	122	205
18. Koillis-Suomi	0.86	0.86	0.42	2.14	7.77	6.32	0.12	433	454	377	104	151	126
19. Lappi	1.92	0.94	1.29	4.15	15.73	4.13	0.40	1 037	610	976	259	190	483
Pohjoispuolisko *Northern half*	5.71	3.89	2.94	12.54	50.72	22.00	1.03	2 892	2 452	2 438	710	665	934
Koko maa *Whole country*	19.13	23.28	15.68	58.09	189.93	173.83	50.82	9 221	14 031	14 013	1 866	2 891	3 396

Taulukko 19. Metsiköiden laatu metsämaalla omistajittain (ilman luonnonsuojelualueita).
Table 19. Quality of stands on forest land by ownership categories (without nature conservation areas).

Omistaja *Owner*	Kehityskelpoiset — *Capable of development*						Vajaatuottoiset — *Low-yielding*					Yhteensä *Total*
	1	2	3	4	5	Yhteensä *Total*	6	7	8	9	Yhteensä *Total*	
	% metsämaan alasta — *% of forest land area*											
	Eteläpuolisko — *Southern half*											
Yksityinen — *Private*	18.5	42.4	6.8	11.3	2.2	81.2	5.4	6.1	0.2	7.1	18.8	100.0
Osakeyhtiö — *Company*	40.1	40.1	1.4	7.5	2.4	91.5	1.5	2.5	0.1	4.4	8.5	100.0
Valtio — *State*	32.0	39.8	1.1	11.3	2.9	87.1	1.2	3.5	3.1	5.1	12.9	100.0
Kunta, seurakunta — *Commune, church*	29.6	43.9	2.3	7.5	2.4	85.7	2.8	4.9	0.2	6.4	14.3	100.0
Yhteisö — *Corporation*	29.2	40.3	3.3	10.3	2.3	85.4	2.7	4.3	0.5	7.1	14.6	100.0
Yhteensä — *Total*	22.0	42.0	5.7	10.8	2.3	82.8	4.6	5.5	0.4	6.7	17.2	100.0
	Pohjoispuolisko — *Northern half*											
Yksityinen — *Private*	19.3	41.9	5.8	9.8	2.4	79.2	7.5	6.4	2.1	4.8	20.8	100.0
Osakeyhtiö — *Company*	31.4	40.3	4.2	8.6	1.7	86.2	3.9	3.5	0.1	6.3	13.8	100.0
Valtio — *State*	21.0	43.0	2.3	9.3	1.9	77.5	3.0	5.8	7.7	6.0	22.5	100.0
Kunta, seurakunta — *Commune, church*	37.0	44.4	2.5	4.9	2.1	90.9	2.4	1.8	0.7	4.2	9.1	100.0
Yhteisö — *Corporation*	21.9	47.0	5.7	7.2	2.1	83.9	3.3	3.1	7.7	2.0	16.1	100.0
Yhteensä — *Total*	20.9	42.5	4.0	9.4	2.1	78.9	5.1	5.9	4.8	5.3	21.1	100.0
	Koko maa — *Whole country*											
Yksityinen — *Private*	18.7	42.2	6.5	10.9	2.3	80.6	6.0	6.2	0.7	6.5	19.4	100.0
Osakeyhtiö — *Company*	38.3	40.1	2.0	7.7	2.3	90.4	2.0	2.7	0.1	4.8	9.6	100.0
Valtio — *State*	22.8	42.4	2.1	9.6	2.1	79.0	2.8	5.4	6.9	5.9	21.0	100.0
Kunta, seurakunta — *Commune, church*	31.5	44.1	2.4	6.8	2.3	87.1	2.7	4.1	0.3	5.8	12.9	100.0
Yhteisö — *Corporation*	24.2	44.9	4.9	8.2	2.2	84.4	3.1	3.5	5.4	3.6	15.6	100.0
Yhteensä — *Total*	21.5	42.3	5.0	10.2	2.2	81.2	4.8	5.7	2.2	6.1	18.8	100.0

1. Hyvä — *Good.*
2. Tyydyttävä — *Satisfactory.*
3. Harsien harvennettu — *Treated by selection cutting.*
4. Hoitoa vaille jäänyt — *Silvicultural measure neglected.*
5. Lepoa tarvitseva — *To be leaved uncut.*
6. Harsintajäte — *Residual of selection cuttings.*
7. Kasvupaikalle väärä puulaji — *Tree species unsuitable for site.*
8. Yli-ikäinen — *Over-aged.*
9. Muu vajaatuottoinen — *Other low-yielding.*

Taulukko 20. Viljelyllä perustetut metsiköt ja niiden laatu metsämaalla omistajittain (ilman luonnonsuojelualueita).

Table 20. Artificially established stands on forest land and their quality by ownership categories (without nature conservation areas).

Omistaja *Owner*	Metsikön laatu — *Quality of stand*					Yhteensä *Total*
	1	2	3	4	5	
	1 000 ha ja % metsämaasta — *1 000 ha and % of forest land*					
	Eteläpuolisko — *Southern half*					
Yksityinen — *Private*	289	17	62	35	26	429
	3.3	0.2	0.7	0.4	0.3	4.9
Osakeyhtiö — *Company*	146	1	22	3	18	190
	13.2	0.1	2.0	0.3	1.6	17.2
Valtio — *State*	71	3	12	1	13	100
	10.1	0.4	1.7	0.1	1.8	14.1
Kunta, seurakunta—*Commune, church*	13	0	2	2	4	21
	5.0	0.1	1.0	0.6	1.4	8.1
Yhteisö — *Corporation*	7		2	0	1	10
	6.5		2.1	0.4	0.5	9.5
Yhteensä — *Total*	526	21	100	41	62	750
	4.8	0.2	0.9	0.4	0.6	6.9
	Pohjoispuolisko — *Northern half*					
Yksityinen — *Private*	92	1	48		4	145
	2.7	0.0	1.4		0.1	4.2
Osakeyhtiö — *Company*	31	1	7		1	40
	11.2	0.2	2.3		0.3	14.0
Valtio — *State*	171	2	66	0	8	247
	4.7	0.1	1.8	0.0	0.2	6.8
Kunta, seurakunta—*Commune, church*	6	0	1	0	2	9
	6.1	0.2	0.9	0.6	2.8	10.6
Yhteisö — *Corporation*	7		2			9
	3.2		0.7			3.9
Yhteensä — *Total*	307	4	124	0	15	450
	4.0	0.1	1.6	0.0	0.2	5.9
	Koko maa — *Whole country*					
Yksityinen — *Private*	381	18	110	35	30	574
	3.1	0.2	0.9	0.3	0.2	4.7
Osakeyhtiö — *Company*	177	2	29	3	19	230
	12.8	0.1	2.1	0.2	1.4	16.6
Valtio — *State*	242	5	78	1	21	347
	5.6	0.1	1.8	0.0	0.5	8.0
Kunta, seurakunta—*Commune, church*	19	0	3	2	6	30
	5.3	0.1	1.0	0.6	1.8	8.8
Yhteisö — *Corporation*	14		4	0	1	19
	4.2		1.1	0.1	0.2	5.6
Yhteensä — *Total*	833	25	224	41	77	1 200
	4.5	0.1	1.2	0.2	0.4	6.4

1. Hyvä tai tyydyttävä taimisto — *Good or satisfactory seedling and sapling stand.*
2. Hoitamaton taimisto — *Untended seedling and sapling stand.*
3. Täydennettävä männyn (tai koivun) taimisto — *Seedling and sapling stand of pine (or birch) in need of supplementary planting.*
4. Täydennettävä kuusen taimisto. — *Seedling and sapling stand of spruce in need of supplementary planting.*
5. Taimistoa varttuneempi metsikkö — *Stand older than in seedling and sapling stage.*

Taulukko 21. Viimeisestä hakkuusta kulunut aika metsämaalla omistajittain (ilman luonnonsuojelualueita).

Table 21. Time from the last cut on forest land by ownership categories (without nature conservation areas).

Omistaja *Owner*	Hakkuusta kulunut aika—*Time from cut*					Hakkaamaton *Uncut*	Yhteensä *Total*
	1 v.—*y.*	2—5 v.—*y.*	6—10 v.—*y.*	11—30 v.—*y.*	31+ v.—*y.*		
	% alasta — % *of area*						
	Eteläpuolisko — *Southern half*						
Yksityinen — *Private*	8.6	24.9	25.5	34.0	6.0	1.0	100.0
Osakeyhtiö — *Company*	5.8	24.6	29.0	34.3	5.4	0.9	100.0
Valtio — *State*	4.1	12.2	19.9	40.3	19.0	4.5	100.0
Kunta, seurakunta — *Commune, church*	7.3	19.7	30.9	37.0	4.5	0.6	100.0
Yhteisö — *Corporation*	9.7	20.9	29.2	34.4	4.9	0.9	100.0
Yhteensä — *Total*	8.0	23.9	25.7	34.5	6.7	1.2	100.0
	Pohjoispuolisko — *Northern half*						
Yksityinen — *Private*	4.1	13.5	15.9	36.8	23.1	6.6	100.0
Osakeyhtiö — *Company*	1.5	17.8	25.7	43.4	7.9	3.7	100.0
Valtio — *State*	1.7	7.1	13.6	26.6	20.6	30.4	100.0
Kunta, seurakunta — *Commune, church*	4.5	14.7	26.2	39.3	12.5	2.8	100.0
Yhteisö — *Corporation*	3.3	5.8	7.0	21.9	37.8	24.2	100.0
Yhteensä — *Total*	2.8	10.4	15.0	31.8	21.7	18.3	100.0
	Koko maa — *Whole country*						
Yksityinen — *Private*	7.3	21.7	22.8	34.8	10.8	2.6	100.0
Osakeyhtiö — *Company*	5.0	23.2	28.4	36.1	5.9	1.4	100.0
Valtio — *State*	2.1	7.9	14.6	28.8	20.3	26.3	100.0
Kunta, seurakunta — *Commune, church*	6.6	18.4	29.7	37.6	6.6	1.1	100.0
Yhteisö — *Corporation*	5.4	10.6	14.1	25.9	27.3	16.7	100.0
Yhteensä — *Total*	5.8	18.3	21.3	33.4	12.9	8.3	100.0

KIRJALLISUUS — REFERENCES

Ervasti, Seppo & Lauri Heikinheimo & Kullervo Kuusela & Veikko Mäkinen. 1969. Suomen metsä- ja puutalouden tuotantomahdollisuudet vuosina 1970—2015. Talousneuvosto. Helsinki.

Ervasti, Seppo & Kullervo Kuusela. 1968. Suomen metsätase vuosina 1953—66. Forest balance of Finland in 1953—66. FF 49.

Heikurainen, Leo. 1971. Metsäojitus ja sen seurausvaikutukset. Metsä ja Puu 9.

Heikurainen, Leo & Kullervo Kuusela & Olavi Linnamies & Aarne Nyyssönen. 1960. Metsiemme hakkuumahdollisuudet. Pitkän ajan tarkastelua. Cutting possibilities of the forests of Finland. A long-term analysis. SF 110.

Huttunen, Terho. 1971. Suomen puun käyttö, poistuma ja metsätase vuosina 1969—71. Wood consumption total drain and forest balance in Finland in 1969—71. FF 127.

Ilvessalo, Mikko. 1959. Suomen maan- ja metsänomistussuhteet 1920—1950-luvuilla. Land- und Waldbesitzverhältnisse in Finnland in 1920—1950ern Jahren. MTJ 51.6.

Ilvessalo, Yrjö. 1927. Suomen metsät. Tulokset vuosina 1921—1924 suoritetusta valtakunnan metsien arvioimisesta. The forests of Suomi (Finland). Results of the general survey of the forests of the country carried out during the years 1921—1924. MTJ 11.

—»— 1942. Suomen metsävarat ja metsien tila. II valtakunnan metsien arviointi. The forest resources and the condition of the forests of Finland. The Second National Forest Survey. MTJ 30.

—»— 1943. Metsänhoitolautakuntain toimintapiirien metsät. II:n valtakunnan metsien arvioinnin tuloksia. Keskusmetsäseura Tapio.

—»— 1948. Nyky-Suomen metsät. Valtakunnan metsien arviointeihin perustuva kuvaus. MTJ 35.5.

—»— 1956. Suomen metsät vuosista 1921—24 vuosiin 1951—53. Kolmeen valtakunnan metsien inventointiin perustuva tutkimus. The forests of Finland from 1921—24 to 1951—53. A survey based on three National Forest Inventories. MTJ 47.1.

—»— 1959. Suomen metsien hakkuumahdollisuudet metsävarojen kehittämiseen tähtäävän hakkuussuunnitteen valossa. Summary in English: Cutting possibilities of the forests of Finland in the light of allowable cut, aiming at the development of forest resources. MTJ 51.9.

—»— 1962. IV valtakunnan metsien inventointi. 1. Maan eteläpuoliskon vesistöalueryhmät. Fourth National Forest Inventory. 1. Southern water system areas. MTJ 56.1.

—»— 1963. IV valtakunnan metsien inventointi. 2. Maan eteläpuoliskon metsänhoitolautakuntien alueryhmät. Fourth National Forest Inventory. 2. Southern forestry board districts. MTJ 57.4.

Koivisto, Pentti. 1966. Itä- ja Pohjois-Hämeen koivuvarat. Birch resources in forestry board districts of Itä-Häme and Pohjois-Häme. FF 24.

—»— 1968. Etelä- ja Pohjois-Karjalan, Itä-, Etelä- ja Pohjois-Savon sekä Keski-Suomen koivuvarat. Birch resources in forestry board districts of Etelä- and Pohjois-Karjala, Itä-, Etelä- and Pohjois-Savo and Keski-Suomi. FF 45.

Kuusela, Kullervo. 1953. Zur Theorie der forstlichen Zuwachsberechnung auf Grund der periodischen Messung. AFF 60.

—»— 1964. Increment-drain forecast for a large forest area. Seloste: Kasvun ja poistuman ennuste suurelle metsäalueelle. AFF 77.5.

—»— 1966. Ålands skogar 1963—64. FF 21.

—»— 1967. Helsingin, Lounais-Suomen, Satakunnan, Uudenmaan-Hämeen, Pohjois-Hämeen ja Itä-Hämeen metsävarat vuosina 1964—65. Forest resources in the forestry board districts of Helsinki, Lounais-Suomi, Satakunta, Uusimaa-Häme, Pohjois-Häme and Itä-Häme in 1964—65. FF 27.

—»— 1970. Suomen eteläpuoliskon metsävarat 1964—68 ja niiden kehittyminen. Forest resources in southern half of Finland in 1964—68 and their development. MTJ 71.1.

Kuusela, Kullervo & Seppo Ervasti. 1969. Reliability comparisons of growing stock, increment and drain estimates in Finland in 1953—1966. MTJ 68.3.

Kuusela, Kullervo & Sakari Salminen. 1969. The 5th National Forest Inventory in Finland. General design, instructions for field work and data processing, MTJ 69.4.

Kuusela, Kullervo & Alli Salovaara. 1968. Etelä-Savon, Etelä-Karjalan, Itä-Savon, Pohjois-Karjalan, Pohjois-Savon ja Keski-Suomen metsävarat vuosina 1966—67. Forest resources in the forestry board districts of Etelä-Savo, Etelä-Karjala, Itä-Savo, Pohjois-Karjala, Pohjois-Savo and Keski-Suomi in 1966—67. FF 42.

—»— 1969. Etelä-Pohjanmaan, Vaasan ja Keski-Pohjanmaan metsävarat vuonna 1968. Forest resources in the forestry board districts of Etelä-Pohjanmaa, Vaasa and Keski-Pohjanmaa in 1968. FF 62.

—»— 1971. Kainuun, Pohjois-Pohjanmaan, Koillis-Suomen ja Lapin metsävarat vuosina 1969—70. Forest resources in the forestry board districts of Kainuu, Pohjois-Pohjanmaa, Koillis-Suomi and Lappi in 1969—70. FF 110.

Linnamies, Olavi. 1971. Metsäteollisuutemme laajennukset ja puuraaka-aineen riittävyys. Expansion of the capacity of Finnish forest industries and the sufficiency of wood raw material. SF Vol. 5, N:o 3: 201—214.

Tiihonen, Paavo. 1966. IV valtakunnan metsien inventointi. 3. Maan pohjoispuoliskon vesistöjen ja metsänhoitolautakuntien alueryhmät. Fourth National Forest Inventory in Finland. 3. Northern water system areas and forestry board districts. MTJ 60.6.

—»— 1968. IV valtakunnan metsien inventointi. 4. Suomen metsävarat vuosina 1960—63. Fourth National Forest Inventory in Finland. 4. Forest resources in Finland in 1960—63. MTJ 66.3.

—»— 1971. Suomen pohjoispuoliskon mäntytukkipuusto v. 1969—70. Das Kiefernstarkholz der Nördlichen Landeshälfte Finnlands i. J. 1969—70. FF 117.

Uusvaara, Arno. 1969. Maan ja metsän omistus Suomessa v. 1965 alussa ja sen kehitys v. 1957—65. Land and forest ownerships in Finland 1965 and their development during 1957—65. FF 63.

Valtakunnan metsien inventoinnin kenttäohje. 1964. Metsäntutkimuslaitos. Metsänarvioimisen tutkimusosasto. Moniste.

ABBREVIATIONS:

AFF = Acta Forestalia Fennica
FF = Folia Forestalia
MTJ = Metsäntutkimuslaitoksen Julkaisuja
SF = Silva Fennica

SUMMARY

FOREST RESOURCES AND OWNERSHIP IN FINLAND 1964—70 AND THEIR DEVELOPMENT 1920—70.

Introduction

The forest resources and ownership conditions are described in this paper on the basis of the results of the 5th national forest inventory carried out between 1964 and 1970, and their development on the basis of the results of 5 inventories carried out in 1921—24, 1936—38, 1951—53, 1960—63 and 1964—70. A detailed description of the method of the 5th inventory can be found in the paper by K u u s e l a and S a l m i n e n, 1969.

The confidence levels of the sampling estimates of the 5th inventory are under analysis and will be published in a separate paper. On the basis of the earlier precision estimates (I l v e s s a l o 1956), the standard error in volume estimate for a minimum area of 10 million hectares does not exceed ± 0.7 per cent and for an average forestry board district ± 3 per cent. The corresponding maximum standard errors for the increment are ± 1 and ± 4 per cent.

Class description

The content of the forest-resource information is described in the paper by K u u s e l a and S a l m i n e n, 1969. The most important descriptions are as follows:

Land classes

F o r e s t l a n d has the potential quality for producing a mean annual increment of at least 1 m³/ha of stem wood including bark, during a rotation of 100 years under favourable stand conditions.

P o o r l y p r o d u c t i v e l a n d has the potential quality for producing a mean annual increment of 0.9—0.1 m³/ha defined as above.

W a s t e l a n d has the potential quality for producing a mean annual increment of less than 0.1 m³/ha defined as above.

R o a d s, d e p o t s, etc.

F o r e s t r y l a n d includes the four classes defined above.

A g r i c u l t u r a l l a n d includes fields, pastures, agricultural roads and the sites of farm buildings.

B u i l t - u p a r e a s include urban and industrial areas and the sites of houses (excluding farm houses).

C o m m u n i c a t i o n r o u t e s, etc., include power lines, air fields and roads outside forestry land.

Sub-classes of forestry land

Mineral site.

Swamp where swamp plants comprise more than 75 % of the ground vegetation and peatland which is transformed from swamp by drainage.

Spruce and pine swamp and peatland.

Pine swamp and peatland.

Open or naturally treeless swamp.

Ownership categories

Private. This category includes holdings owned by private individuals, private firms, heirs and those under tenancy contracts.

Company (excluding housing companies).

State. This category includes land administered by the National Board of Forestry, the Forest Research Institute and other State agencies.

Commune and Church.

Corporation comprises land owned by foundations, co-operative organisations, limited partnerships, housing companies and other corporate bodies.

Site-fertility classes

1. Very rich sites. On mineral sites the vegetation is characterized by leaf mosses, long-stalked herbs, grasses and ferns; on peatland by brown mosses, leaf mosses, herbs, grasses and ferns.

2. Rich sites. On mineral sites the vegetation is characterized by herbs and grasses; on peatland by herbs.

3. Damp sites. On mineral sites the vegetation is characterized by grasses, feather mosses and dwarf-shrubs; on peatland by *Myrtillus* shrub and long-stalked sedges.

4. Sub-dry sites. On mineral sites the vegetation is characterized by feather mosses, dwarf-shrubs and lichen; on peatland by *Vaccinium* shrub and oligotroph sedges.

5. Dry sites. On mineral sites the vegetation is characterized by dwarf-shrubs, heather and lichen; on peatland by cotton-grass and dwarf-shrubs.

6. Barren sites. On mineral sites the vegetation is characterized by lichen, dwarf-shrubs and an almost complete absence of herbs and grasses; on peatland by *Sphagnum fuscum* moss.

Tax classes of sites

IA: very rich and rich sites
IB: damp sites
II: sub-dry sites
III: dry and barren sites and spruce and pine swamps on forest land
IV: pine swamps on forest land
V: most of the poorly productive land
J: waste land.

If the site productivity is reduced markedly by stones, paludification, etc., the tax class defined above can be lowered.

Degree of transformation of peat site after drainage

S w a m p i n n a t u r a l s t a t e.
D i t c h e d swamp, recently drained.
T r a n s f o r m i n g peat site, always forest land.
T r a n s f o r m e d peat site, always forest land, and having reached the stage of full productivity after drainage.

Land

The land area of Finland by principal land-use classes and mineral sites and peatland by classes are presented in Tables 1, 2 and 3 and the development of forestry land in Table 4. The area of forest land comprises 61.2 % and forestry land, including forest, poorly productive and waste land, comprises 87.3 % of the total land area. The area of peatland is 36.7 % of the total forestry land and 59.5 % of it is poorly productive and waste-land swamps.

Land- and forest-ownership conditions are described in Tables 5, 6, 7 and 8, Figures 2 and 20 and Appendix Tables 1 and 2. The most conspicuous feature in the development of the ownership conditions is the decrease of the State and company forests and the increase of private forests as a result of settlement activity and establishment of new farms.

Detailed land descriptions are presented in Table 9, Fig. 3 and in Appendix Tables 3—8.

Swamp drainage, the most important land-improvement measure (Tables 10 and 11, Fig. 4 and Appendix Tables 9 and 10), covered 3.1 million ha in 1967 and approximately 4.3 million ha at the end of 1971.

Growing stock

Tree-species dominance (Tables 12 and 13 and Appendix Tables 11 and 12) and its development is characterized by the increase of stands dominated by spruce and decrease of stands dominated by deciduous species. However, in the northern half of the country stands dominated by pine are increasing at the expense of the stands dominated by spruce and deciduous species.

The age-class structure of the growing stock and its development is presented in Tables 14, 15 and 16, in Appendix Tables 13 and 14 and in Figures 5 and 6. The establishment of new stands, especially those of pine, commenced in 1960s. The shortage of young stands dominated by deciduous species is a conspicuous feature in the age-class structure. During the last 50 years, the development of the tree-species composition and age-class structure has been characterized by a process of tree-species dynamics: the initial stage involved the dominance of young and middle-aged stands of the pioneer species pine, birch and alder, which regenerated on the last open areas resulting from agriculture on burnt-over clearings and from tar burning and forest fires, and the later stage consisted of the penetration of spruce into the stands of the pioneer species, assisted by the harvesting of pine and birch. Although the young age classes have increased considerably through regeneration cuttings, the amount of mature and nearly mature stands is great and the harvesting possibilities of mature timber are good in the near future. Similar conclusions can also be made on the basis of the development-class structure of the growing stock (Table 17, Appendix Tables 15 and 16 and Figures 7 and 8).

Growing-stock volume by tree species and the development of the growing volume are presented in Tables 18—23, Appendix Tables 16 and 17 and Figures 9—12. In spite of extensive utilization of timber resources, the growing-stock volume has not changed substantially during the last 50 years. The drop in the growing-stock volume in 1944 was caused by Finland's loss of territory. During the war and up to the beginning of 1950s, the volume increased because of the small utilization of wood. Since 1960, the drain has exceeded the increment and the growing-stock volume has decreased. As a long-term development, the proportion of spruce is increasing and the proportion of deciduous species, especially of birch, is decreasing.

As a consequence of the age-structure development and of the adoption of silvicultural thinnings during the 1950s and 1960s, the saw-timber resources have increased considerably (Tables 24, 25, 26, 27 and 28, Figures 12 and 13). Consequently the structure of the growing stock has improved from the point of view of reducing the expenses in mechanized logging.

Increment, allowable drain and timber balance

The gross increment of the growing-stock volume, excluding bark, per annum, and its development are presented in Tables 29, 30 and 31 and in Figures 9, 10 and the increment including bark in Table 32. Because of intensive forest-improvement and silvicultural work (Fig. 14), the increment is comparatively large. In the southern half of the country, the increment percentage is 4.5, in the northern half 2.6 and in the whole country 3.9 (Table 30). The increment will increase in the future due to the improvement work and new young tree stands. On the basis of the increment and drain relationship of different tree species, the volume of spruce will increase, especially in the southern half of the country, and the volume of deciduous species will decrease more noticeably than in the past.

In conditions where there is an abundance of mature stands and stands approaching maturity, intensified silvicultural and forest improvement activity immediately increases the allowable drain on the basis of sustained yield. Because of this, the allowable drain is estimated to be 49.84 million m^3, excluding bark, per annum (Table 33 and Figures 17 and 18), which is 2.24 million m^3 greater than the increment estimate. The allowable drain, including bark, is presented in Table 35, and the proportions and amounts of the principal timber assortments in Table 34 and in Appendix Table 18.

Reliability comparisons of growing-stock, increment and drain estimates are presented in Table 37 and Fig. 16 (more details in the paper by K u u s e l a and E r v a s t i, 1969). The basic estimates of the timber balance have relatively good conformity and reliability provided they are not calculated for too small areas. However, discrepancies between estimates for the northern half of the country are so great that they can hardly fall within sampling-error limits. The growing-stock volume in the north has decreased more than it should have on the basis of increment and drain estimates.

In the northern half of Finland, the mean annual drain during 1953—70 equals approximately the annual increment and is 2 million m^3 smaller than the allowable drain. The drain of spruce has been 3 million m^3 smaller and the drain of deciduous species 2 million m^3 greater than the allowable drain. The use of spruce should increase and the use of deciduous species should decrease in the future. In the northern half of the country, there is overcutting and the drain of pine should decrease by 1.5 million m^3 (Figures 17, 18).

As a whole, at the end of 1960s the drain equaled the estimated allowable drain. However, there are large areas where the drain has exceeded the amount of the yield on a sustained basis. In other large areas, the harvesting possibilities have not been fully utilized. Stands of mature timber are accumulating especially in south-western parts of the country. This tendency may be emphasized by the need of urban population to preserve mature timber as part of the recreational landscape. A similar phenomenon is the conservation of mature timber stands in the northern protection forests and on high hills, and the increase in the area of national parks (Table 36 and Fig. 15).

Silvicultural quality of stands and recurrence of cuts

Data describing the silvicultural quality of stands are presented in Tables 39, 40 and 41 and in Appendix Table 19, and recurrence of cuts in Fig. 19. Although the quality of stands has improved considerably during the last 15 years, the area of low-yielding stands is alarmingly large. Commencing and financing a necessary improvement programme, especially in private forests, is still an unsolved problem.

Forest ownership

The forest ownership conditions and their development, presented in the many tables mentioned earlier, are summarized in Fig. 20. The most conspicuous feature is the decreased proportion of State and company forests and the increase of private forests. This change has been caused by the settlement of landless population, an activity which was exceptionally great after the war when new farms were established for the agricultural population from the ceded areas. The new farms were established on those parts of State and company forests which were on the most fertile sites with an abundance of mature timber.

During the last 50 years, the forest land owned by the State has decreased by 33 per cent and the growing-stock volume by 48 per cent. At present, State forests comprise only 12 per cent of the total timber-producing capacity. Besides this, the State forests are located in areas with the most disadvantageous logging conditions in the northern and eastern parts of the country.

The private forests comprise 78 per cent of the timber-producing capacity. The ownership of forest-industry companies accourits for 6.1 per cent and communes, Church and corporations 3.3 per cent of the timber-producing capacity.