INCREMENT-DRAIN FORECAST FOR A LARGE FOREST AREA

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SELOSTE:

KASVUN JA POISTUMAN ENNUSTE SUURELLE METSÄALUEELLE

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Preface

This paper includes the results of the research project No. E8—FS—30 under United States Public Law N:o 480, 83rd Congress (The Agricultural Trade Development and Assistance Act of 1954). The research funds have been granted to the *Institute of Forest Mensuration and Management of the University of Helsinki*.

During the time of the project I have had a chance to co-operate closely with professor AARNE NYYSSÖNEN, Director of the *Institute of Forest Mensuration and Management*. He has given many valuable suggestions to the work. For this I wish to express my sincere gratitute to him.

Of the research assistants, Mr. CHRISTIAN KEIL, B. of For., has been working with the basal area — height method, Mr. PEKKA KILKKI, B. of For., with the increment percentage functions, and Mr. KALEVI SAARINEN, B. of For., with the estimation of timber products in the growing stock and allowable cut. I am indebted to their assistance.

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Kullervo Kuusela

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Introduction

Yield Table Methods

A yield table shows usually the stand volume, intermediate cut and mortality per unit area and often many additional characteristics at different ages for even-aged stands by tree species and site classes. Yield tables have been widely used in increment forecasts, for which they are practical and accurate concerning even-aged stands under regular treatment.

Normal yield tables show the development of volume in fully-stocked stands and variable density tables the development in under-stocked stands. If the table shows the volume of standing trees only at different ages, it gives the net increment under specified conditions. Estimates of gross increment requires additional information on cut and mortality.

Because the actual stands have a large variation in stocking and treatment, the yield table volumes must be adjusted to the actual conditions, especially to the actual density. In the American usage the degree of stocking is often measured as a density ratio. It is compared with the fully-stocked stands by the ratio of the basal area (or volume) per unit area of the actual stand to the same characteristic of the equivalent normal stand. In addition to density, the site class, tree species and age are needed in using yield tables.

The adjustment of the yield table values for differences in density is necessary because the under-stocked stands grow with a greater increment percentage than the fully-stocked stands. In many methods it is assumed that the under-stocked stands develop towards a fully-stocked state and the effect of this on the increment can be estimated on the basis of permanent sample plot measurements (MEYER 1933; BRIEGLEB 1942; SEIP 1953). A method of adjusting the increment from normal yield tables and for taking account of the growth toward a fully-stocked state is developed by GEHRHARDT (1930), GEVORKIANTZ (1937) and DUERR (1938). In the method of GEVORKIANTZ and DUERR (1938) the additional stand characteristics are the average diameter of the main stand and the merchantability ratio.

The yield-table method is more or less a stand-wise procedure. In a large forest area it can provide only rough estimates because the growing stock is usually composed of numerous stands with varying species composition and degree of stocking. It can be used particularly in conditions where the bulk of the stands are established artificially, e.g. in Great Britain (Working Plans Code, 1960). Stands are grouped by age classes and the area of each age class is decreased to account for natural losses or other deductions and the area under yield forecast is considered as fully stocked.

Stand-Table Methods

In the stand-table method the increment forecast is prepared by diameter classes and usually by tree species. The volume increment may be estimated separately for the trees in each diameter class. Another way is to calculate the volume increment in each class as the volume of ingrowth (trees which pass the lower class boundary during the period) plus the increment of the trees which remain in the class minus the volume of those trees which pass the upper class boundary. A third way is to construct a new stand table and the increment is found as volume of the new stand table minus the present volume (Petrini 1948; Spurr 1952; Kuusela 1958; etc.).

The diameter increment in each class is usually measured by borings and the change in bark thickness is presented as a function of the diameter excl. bark. The increment of bark can be correlated with the increment excl. bark (Petrini 1948, p. 111).

The future diameter of the current trees can be calculated on the basis of several assumptions: 1. The diameter increment is presumed to be as great as it has been in the past. 2. The diameter increment is presumed to be as great as it has been in trees of the same size in the past. 3. The basal area increment is presumed to be constant during the measurement and forecast period. 4. The development of the periodic increment in the past is extrapolated into the future.

The diameter increment may be added to the diameter of the mid-class tree or the construction of a new stand table may be based either on the assumption that the distribution of trees is even in each class or that the distribution is dependent on the present class frequency curve. The height-diameter relationship may be taken as being unchangeable during the forecast period or a new height curve is prepared using the height increment data.

Effect of the ingrowth from below the minimum callipering limit, mortality and cut during the forecast period raise many problems. Mortality can be estimated by diameter classes or as a lump sum and the estimation can be based on existing plot data or on a tally of the trees which are assumed to die during the forecast period.

Any type of the stand-table method is laborious if compared with the expectable results in cases of a large growing stock. It is best suited in investigations where the value increment and passage of the trees from one diameter class into another are the topics.

Increment Functions

Increment forecast can be based on functions (regression equations) where the increment is used as the dependent variable and other suitable stand characteristics are used as independent variables (e.g.: site, age, height, basal area, volume, diameter, diameter class frequency, number of trees per unit area, number of years since the last cutting, etc.). These methods have been called stand structure methods because the variables describe the structure of a stand in one way or an other (Nyyssönen 1956). Increment has been usually expressed in volume measure.

Spurr (1952) provides a comprehensive summary of the studies to develop increment functions. Samples of these investigations consist mostly of fully-stocked stands for which linear correlation methods have been used. Lexen (1943) used the bole area of the trees as the independent variable. According to him, it portrays better than the board foot volume the growth potential of a cut-over stand. Herrick (1944) found the growing-stock volume to be the best independent variable in multi aged oak-hickory stands. Warrack (1959) found that the top height explained about 30 % of the variation in increment of Douglas fir stands while age, density, etc., offered nothing valuable (cf. Hummel and Brett 1950). The fact that the increment in fully-stocked stands within a rotation period is mainly dependent on the stand height is known in Middle-European literature as the law of Eichorn (Schober 1955; Erteld 1957; Möller 1959). Vuokila (1960) found that the top height and basal area are the most promising characteristics. Buckman (1962) has used basal area, age and site index as independent variables with basal area increment as the dependent variable.

Obviously the multiple regression analysis and increment functions offer good ways to solve the forecast problems. In most investigations carried out so far the stands have been fully or almost fully stocked and treated with silvicultural thinnings. In these stands the height seems to be the most important independent variable. On the other hand, in under-stocked and selectively-cut stands the height loses much of its importance.

Increment Percentage Methods

Increment percentage methods have been mainly used in Scandinavia and Finland (Jonson 1928; Ilvessalo 1942, 1956). They were introduced when forestry practices were extensive and their primary importance is based on an easy application to practical forestry. The volume increment percentage (p_v) is calculated as the of the basal area percentage (p_g) and heightform increment percentage (p_{hf}):

$$p_v = p_g + p_{hf}$$

Diameter and height increment are estimated in the field and the effect of the form increment is inferred empirically (ILVESSALO 1948).

Although the simplicity of the method in regard to measurement and calculation technique is partly ostensible, the increment percentage has the advantage of being little dependent on the site and even on tree species (HAGBERG 1943; ILVESSALO 1948). In increment forecasts it has often given rise to serious errors, especially underestimations, but the fault has lain more in erroneous methods than in the percentage itself (KUUSELA 1953, 1958).

The general usage has been to measure and calculate the increment percentage of sample plot stands and adjust the percentages as a function of the age. In the Swedish National Forest Inventories the increment percentages are calculated on the basis of the volume increment obtained as the difference of the tree volume at the time of measurement and five years earlier. The percentage values have been adjusted graphically, the increment of the trees cut during the measurement period has been estimated separately and the total volume increment and the corresponding increment percentage have been analysed by increment regions, site and density class, tree species and stand age (NILSSON 1961).

In increment forecast the percentage for each age class has been taken from the percentage series against age. The annual increment multiplied by the number of years in the forecast period gives the periodic increment. This is the way in the »rental cut method» developed by LIHTONEN (1943) and widely used in Finland (LIHTONEN 1946; ILVESSALO 1956; LINNAMIES 1959). Increment and cut are forecast by age or development classes. Another form of the percentage method has been used in a cutting budget method called stock development forecast (KUUSELA 1958 a, 1959; HEIKURAINEN, KUUSELA, LINNAMIES and NYYSSÖNEN 1960). The latest form of the Finnish cutting budget is a method in which the desirable growing stock has an essential role (KUUSELA and NYYSSÖNEN 1962). The method is based on the inventory data of the current stock, description of the desirable stock constructed by yield tables and determining the temporary desirable stock at the end of the forecast period. The calculation procedure is accomplished by using the compound interest factor obtained from the increment percentage series as a function of age (PETRINI 1957). A further improvement in this method is to calculate the compound interest factor directly from the increment and drain data. The compound interest factor calculated in this way and called »increment intensity index» will be the key concept in this paper (Cf. the later section »Increment Forecast Methods in Finland», p. 60.).

Basal Area — Height Methods

The two-way method for the increment forecast presented by SPURR (1952, 1954) may be considered the first basal area — height method based on precise

foundations. Its great advantage is that the two main elements of the volume increment, the basal area and height increment, are analysed separately because of their being both capable of precise definition and simple objective determination.

In the two-way method the basal area and height increment are considered in terms of net increment. Development of height is presented by curves against age by site classes. The basal area increment is estimated from empirical data or increment borings by diameter classes. Future increment is based on the assumption that the basal area increment per tree closely approximates a straight line for a major portion of the tree's life span (an assumption obviously tenable only in more or less fully stocked stands).

Mortality is estimated from empirical data or its effect is partially eliminated by restricting the calculating process to the dominant trees which mostly survive the forecast period.

The future volume is calculated by assuming that its ratio to the current volume equals the ratio of the product of the basal area and height in the future to the product of the basal area and height at present.

The world-wide introduction of the relascope method of BITTERLICH greatly facilitates the estimation of the basal area and mean height. Thus a further development of the two-way method may prove useful.

Continuous Inventory Method

The continuous inventory method, arising from the control method (e.g., KNUCHEL 1950), is based on comparatively accurate, repeatedly carried out growing-stock inventories and felling statistics. If the current volume (V_o), volume *n* years ago (V_{-n}) and drain during n years (D) are known, the increment (I) is

$$I = V_o - V_{-n} + D$$

The volume increment can be broken down into tree species, age classes, diameter classes, etc.

If data from several inventories are available, the trend of the growing stock, drain and increment development can be determined and extended into the future. If the past treatment of the growing stock will continue unchanged in the future, there is no need to prepare special increment forecasts. On the other hand, the increment forecasts are urgently needed if the amount of drain and the cutting methods are changed in the future.

The continuous inventory method has been used mainly in very intensive forestry and in cases of comparatively small forests. Lately it has been adopted in the Swedish National Forest Inventories and it will obviously come into more general use (e.g., ARMAN and HAGBERG 1962).

Conclusions and Outlines of the Work

Basic Principles

In the first stage of forestry as an economic activity the timber production is based on the exploitation of existing forest capital without any consideration of the growth of the trees. Tree volume is likened to beds or veins of coal; when one source is exhausted the miners must seek a new supply. At this level of forestry there is no need to forecast increment.

In the second stage the old-growth virgin stands are cut to such an extent that their exploitation cannot provide enough timber to meet the increasing consumption. The young stands composed of trees smaller than the commercial size and the cut-over residual stands acquire an expectation value because of their growth. The exploiters have to ask what the expectable volume of trees is after 10 or 20 years or how many years they have to wait until the uncommercial stands are grown to an exploitable size. The gross increment during a period of time is of minor importance while the net increment (gross increment minus mortality) is the key concept. The current volume of timber is known and the future volume after a period of time is sought. The volumes are usually expressed in commercial units of measure. The planning of future cuttings involves increment forecasts but the forestry has not reached the stage of conscious utilization of all possibilities to grow trees. Increment forecast methods are mainly developed for a standwise procedure during a period with no other drain but mortality. In cases of understocked stands without partial cutting during the forecast period, a trend of development toward normality is estimated. If the stand will be partially cut during the period a regular treatment is usually presumed.

In the third stage of forestry the need for timber exceeds the available resources. The stands are constantly under cutting operations and old stands are replaced by new seedling stands. The forest manager asks what the current gross increment is, what it will or could be in the future, and how much he can cut timber on a sustained and progressive basis. His aim is to harness all site qualities for growing trees. He wants to harvest more timber while reducing the cutting residues and mortality. The volume of trees is termed the growing stock and is an organic producing element which shall be maintained in a predetermined composition and quantity in order to perpetuate the full utilization of the site. As said, the future volume is predetermined or is at least optional. The current and the future growing stock can be considered known quantities. The main object in the management planning is the drain which can be harvested because of the increment.

In this investigation »the large forest area» is considered to be large enough to maintain a growing stock composed of many stands at different ages, development and treatment classes, containing many tree species and growing on different sites. The growing stock is large and heterogenous and it can be divided into

groups or statistical strata for inventory and management planning purposes. Though the stands in each stratum are more or less alike, every stratum is usually much more heterogenous than a single stand. Thus the increment forecast methods developed for a single stand may not be suitable for the growing stock of a large forest area.

In an individual stand the increment forecast can cover a period of time without cut or even without any mortality. In a large forest area and during any period of time there is always mortality and, if the forests are in commercial use, cutting drain too. Thus the increment can not be separated from the drain. In other words, the increment forecast of a large forest area involves the increment-drain process and it can be called the increment-drain forecast. In a planned forestry it is the same as a cutting budget, a harvesting plan and a prescribed order of measures to develop the growing stock on the basis of sustained and progressive yield.

The increment-drain forecast is based on the inventory data of the current growing stock, on data concerning the desirable stock in the future and increment intensity in the conditions concerned. The three characteristics mentioned, current stock, desirable future stock and increment intensity, can be considered as independent variables and the drain as the dependent variable estimated by increment-drain forecast. Although the actually needed cut may sometimes be greater than the forecast drain and the desirable growing stock is not attained, the future growing stock at the end of a forecast period in planned forestry is still an optional quantity. There must be a minimum growing stock to maintain the production of timber.

Units of Measure

In the American usage the increment is mostly expressed in commercial or technical units of measure (board foot, etc.), but in Finnish and Scandinavian usage almost exclusively in units of the true bole volume from stump (or from ground) to the top of the tree. From the point of view of the cutting budget the ideal unit of measure should have a meaning and value for the management planning now and in the future. Uses of wood and specifications of timber products are constantly changing. The up-to-date commercial units of measure at the beginning of the forecast period may be entirely out-dated at the end of the period and the value of the increment-drain forecast expressed only in commercial units may have decreased.

»The cubic foot volume of the bole is a valid measure. Board foot volume is not because it is affected by arbitrary assumptions concerning the use to which the wood will be put. Ingrowth of the embryo of the board feet during a period give no indication of the growth potential.»

»All growth measurements should be based on straight cubic foot basis, converting these cubic values to an economic basis such as board-foot measure whenever such values are required.» (SPURR 1952, p. 206).

A logical continuation to the quotation above is to express the volume in increment estimation without any limiting diameter either at top or in callipering at breast height, because such limiting diameters are also »affected by arbitrary assumptions concerning the use to which the wood will be put». If the initial volume, increment, drain and final volume are in terms of the total bole volume from stump or ground to the top of the tree the results of the increment forecast will always be up to date from the point of view of the measurement unit. The specifications of the usable wood at present determine the economic value of the volume now and the specifications in the future determine the value of the volume at the end of the forecast period.

For management planning purposes the bole volume may be expressed either with or without bark. Recommendations of IUFRO to standardize the units of measure obviously increase the use of volume with bark.

In management planning the available wood is needed in timber products. Therefore the growing stock and allowable cut will be described in terms of those stock characteristics from which the amounts of timber products can be deducted.

The larger the forest and the longer the forecast period the less of value are the increment and allowable cut expressed in timber products, because their accuracy in regard to future market conditions is not very great. Thus the safest unit measure in an increment forecast is the true bole volume in cubic meters or cubic feet which is then converted into commercial units on the basis of specifications in force at the time in question.

Outlines of the Work

The most important fact to consider in attempting to develop an increment forecast method is the great dependency of the increment on the growing stock volume. Although the site (soil and climate) produces the increment and volume there would be no increment without the volume as an increasing capital. The cutting possibilities are still more dependent on the existing growing stock. Thus the primary characteristic in management planning is the growing stock volume. The estimates of the increment lose much of their accuracy if made without the volume.

As a methodological starting point, the increment is considered the dependent variable which can be explained by other growing-stock characteristics as independent variables among which the growing-stock volume should always be. But should the increment be expressed in volume measure or as percentage?

If the growing-stock volume is considered a necessary independent variable,

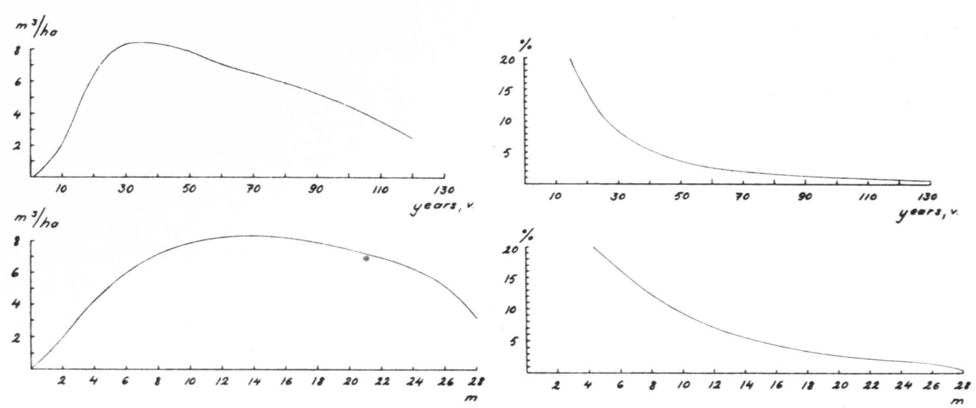

Fig. 1. An example of the development of the annual increment in cubic measure and as percentage against age and dominant height.

Kuva 1. Esimerkki vuotuisen kasvun ja kasvuprosentin kehittymisestä iän ja valtapituuden funktiona.

there is no difference in principle in using either increment in volume measure or as percentage. When I stands for increment, V for growing stock volume, and p for percentage, the increment percentage is a function of some stock characteristics as follows:

$$p = 100 \frac{I}{V} = f\,(age,\ height,\ site,\ etc.)$$

or

$$I = f\,(\frac{V}{100},\ age,\ height,\ site,\ etc.)$$

If the increment percentage can be explained as a function of some stock characteristics excluding the growing-stock volume, the increment in volume measure is explained by the same characteristics plus the growing-stock volume.

Increment percentage was mentioned earlier as being peculiarly independent of the site, and this has been considered a great advantage from the point of view of the increment forecast. From the methodological point of view the percentage has another advantage which is illustrated in Fig. 1.

Increment percentage against age (or height) is a hyberbola or a logarithmic curve and increment in volume measure a much more complex curve. Obviously the analytic explanation of the increment percentage function is easier than the explanation of the increment function.

For the reasons presented above, the basis of the analysis and the primary object of this investigation is the increment percentage. Using available and measured sample plots the increment percentage will be analysed as a dependent variable explainable by other growing stock characteristics.

The main emphasis will be on the methods which can be used in connection with the interacting increment and drain. For example, if the basal area — height method is used and the increment of basal area and height are treated separately, a workable forecast method is a complex problem because the cut during the forecast period may change the height in a drastic and arbitrary way. The same difficulty is encountered when the height is taken as the independent variable for increment percentage function. However, the introduction of the relascope and the easy measurability of the relascope stock (Kuusela 1960) gives cause to develop the basal area — height method.

An increment-drain forecast should give at least approximately the allowable cut in timber products. Thus it will be attempted to find the stock characteristics determining the amounts of timber products. Besides the topics mentioned above, some other aspects are also of interest. In the increment forecast method the climatic fluctuations and their effect on the increment are to be taken into account. The basic data needed for an increment-drain forecast must be measurable in a forest inventory or attainable from other sources. These and some other aspects are the secondary topics of this investigation.

Theory and Basic Concepts of the Increment-Drain Process

Quantities of the Increment-Drain Process

The increment-drain process is regarded as occurring during a period of n years and the drain, if any, is concentrated in the middle of the period. If $n/2 = m$, the drain in the calculation procedure occurs at the end of the half-period of m years. The whole process (Lönnroth 1929) and its quantities are illustrated in Fig. 2.

At the beginning of the forecast period there is the initial volume (v). In the event that drain occurs during the period, the initial volume is divided into two parts: the initial volume of the final stock (v_E), i. e. the initial volume of those trees which will form the growing stock at the end of the period; and the initial volume of the drain (v_D), i.e. the trees which will comprise the drain.

The initial volume of the final stock grows during the forecast period to the final volume (V) at the end of the period:

$$v_E + I_E = V \qquad (1)$$

where I_E is the increment on the final stock. It includes the volume of ingrowth if there is any.

The initial volume of the drain (v_D) grows to the volume of the drain (D) at the end of the half-period of m years:

$$v_D + I_D = D \qquad (2)$$

where I_D is the increment on drain, including the possible ingrowth.

There are often two components in the drain: the cut (C), i. e. the volume of those trees which are cut during the period; and the mortality (M), i.e. the vol-

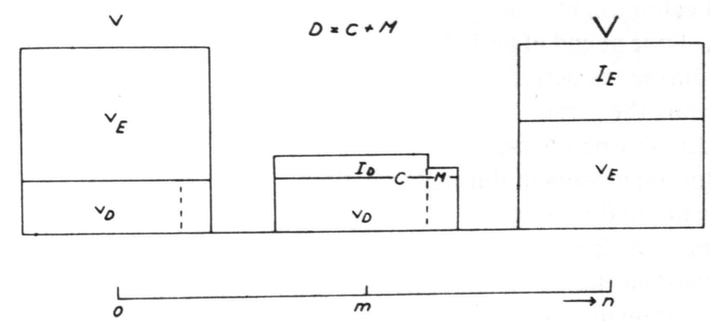

Fig. 2. Increment-drain process during a period of n years.

Kuva 2. Kasvun ja poistuman tapahtuma n-vuoden pituisen jakson aikana.

ume of the trees which die from natural causes during the period. Increment on drain may similarly consist of the increment on cut (I_C) and the increment on mortality (I_M). Thus

$$I_D = I_C + I_M \tag{3}$$

The total increment (I) during the forecast period is:

$$I = I_E + I_D \tag{4}$$

Another important formula for the total increment is:

$$I = V - v + D \tag{5}$$

When there is mortality but no cut, the total increment is:

$$I = I_E + I_M = V - v + M \tag{6}$$

When there is no drain the total increment is:

$$I = V - v \tag{7}$$

The increment concidered above is often called gross increment. Net increment (I_N) is an important quantity in the American forecast methods for periods without any cut. It is calculated by the formulae:

$$I_N = V - v = I - M \tag{8}$$

A useful formula for calculating drain is:

$$D = v + I - V \tag{9}$$

Summary of Quantaties and Their Symbols

v = initial volume at beginning of forecast period
v_E = initial volume of final stock
v_D = initial volume of drain
v_C = initial volume of cut
v_M = initial volume of mortality
V = final volume at end of period
D = drain during the period
C = cut during the period
M = mortality during the period
I = total (gross) increment during the period
I_E = increment on final stock
I_D = increment on drain
I_C = increment on cut
I_M = increment on mortality
I_N = net increment
n = number of years in forecast period
m = number of years in half-period ($m = n/2$)

An Increment Intensity Index

Increment percentage is the ratio of the annual increment to the growing-stock volume. The increment can be expressed by a derivative of percentage which is called in this paper increment intensity index. It can be inferred from the compound interest factor used in the cutting budget calculation (PETRINI 1957; KUUSELA and NYYSSÖNEN 1962). According to the usage described in the papers mentioned above, an annual increment percentage p is taken as being in force for a growing stock during a period of n years (Fig. 3) and the rate of growth is assumed to equal the rate of compound interest. The increment-drain process has the following form during the period of n years while $n/2 = m$:

$$(1.0p^m\, v - D)\, 1.0p^m = V \tag{10}$$

and further

$$D = 1.0p^m\, v - \frac{V}{1.0p^m} \tag{11}$$

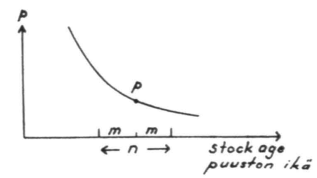

Fig. 3.

Kuva 3.

The method of inferring the factor $1.0p^m$ directly from series of annual increment percentage (PETRINI 1957) is based on the supposition that the rate of growth equals the rate of compound interest. However, the actual rate of growth in young stands is greater than the rate of compound interest. Later it equals the rate of compound interest and in old stands it is lower than the rate of it (KUUSELA and NYYSSÖNEN 1962). The difficulty caused by the changing rate of growth can be eliminated by inferring the increment intensity index from formula (11). It is:

$$1.0p^m = \frac{D \pm \sqrt{D^2 + 4vV}}{2v} \tag{12}$$

The series of the intensity index can be calculated from the yield table data and sample plot measurements. It can be investigated as a function of stock characteristics.

As defined above, the increment intensity factor is a function of the initial volume, final volume and drain. There is a great deal of increment data measured by periods with no drain and the index is to be calculated on the basis of the initial and final volume. An index $1.0p^m$ is in effect during the period of n years (Fig. 4). During the first half-period of m years the initial volume v grows to V' ($= 1.0p^m v$) and during the second half-period V' grows to V ($1.0p^m V'$). Consequently,

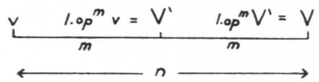

Fig. 4.
Kuva 4.

$$(1.0p^m)^2 v = V; \tag{13}$$

$$1.0p^m = \sqrt{\frac{V}{v}} \tag{14}$$

Sometimes the index is calculated from increment data with a period of n years but the index is needed for a forecast period of $2n$ years: e.g., the increment measurement period is 5 years and the forecast period is 10 years. The index $1.0p^m$ decreases as a function of increasing age as illustrated in Fig. 5. The indexes $1.0p_1^m$ and $1.0p_2^m$ are known and $1.0p^{2m}$ is wanted. Referring to formula (13),

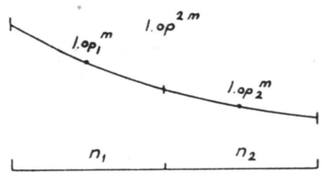

Fig. 5.
Kuva 5.

$$1.0p^{2m} = 1.0\ p^m{}_1\ 1.0p^m{}_2 \tag{15}$$

As mentioned earlier, in planned forestry the initial volume v is known, the desired (or optional) final volume is determined in advance and the drain during the forecast period is sought. However, there are cases when the drain is known from an advance estimate and the final volume and net increment are wanted. Solved from formula (10):

$$V = (1.0p^m)^2 v - 1.0p^m D \tag{16}$$

An estimate of the total annual current increment can be calculated by the increment intensity index, too. It is the function of the characteristics of the current growing stock:

$$I_{annual} = (1.0p^m v - \frac{v}{1.0p^m}) : n \tag{17}$$

Summary of the Formulas for Increment-Drain Forecast

The initial volume (v) is known, the final volume (V) at the end of forecast period is determined in advance, the increment intensity index ($1.0p^m$) is estimated as a function of the stock characteristics in the middle of the forecast period of n years ($m = n/2$), and the drain (D) during the period is wanted:

$$D = 1.0p^m v - \frac{V}{1.0p^m} \tag{11}$$

If the increment in volume measure is known, the drain is:

$$D = v + I - V \tag{9}$$

The initial volume is known, the drain is estimated in advance and the final volume is wanted:

$$V = (1.0p^m)^2 v - 1.0p^m D \tag{16}$$

The total (gross) increment (I) during the forecast period is calculated by the formula:

$$I = V - v + D \tag{5}$$

The net increment (I_N) is calculated by the formula:

$$I_N = V - v = I - M \tag{8}$$

Examples

In the following examples illustrating the theory developed in this part of the paper, the increment intensity index is a function of stock age (t) and average stock volume (v) during the forecast period (KUUSELA and KILKKI 1963):

$$1.0p^m = f(t, v)$$

At the time of measurement the age of a growing stock is 62 years and its volume (v) is 174 m³/ha. The desirable volume (V) after a 10-year period (when the age is 72 years) is 200 m³/ha. The age at the middle of the period is 67 years and the average volume during the period or approximately at the middle of the period is (174 + 200) : 2 = 187 m³/ha. The $1.0p^5$ as a function of $t = 67$ and $v = 187$ is 1.1790 (see later section entitled »Material for Increment Percentage Functions»).

a) The allowable drain (D) and the total increment during the period (I) are wanted. They are calculated by formulas (11) and (5):

$$D = 1.1790 \times 174 - 200/1.1790 = 35.5\ \text{m}^3/\text{ha}$$

$$I = 200 - 174 + 35.5 = 61.5\ \text{m}^3/\text{ha}$$

b) The current age is 67 years, the volume at his age is 187 m³/ha and the index $1.0p^5$ is 1.1790. An estimate of the current annual increment is wanted (17):

$$I_{annual} = (1.1790 \times 187 - 187/1.1790) : 10 = 6.19\ \text{m}^3/\text{ha}.$$

c) At the age of 72 the volume is 200 m³/ha. It is assumed that there is no drain during the next 10-year period. $1._0 p^5$ is $1._{1328}$ as a function of $t = 77$ and of the average volume, approximately 230. The volume after the 10-year period is wanted (13):

$$V = (1.1328)^2 \times 200 = 256.6 \text{ m}^3/\text{ha}$$

The forecast increment is (7):

$$I = 256.6 - 200 = 56.6 \text{ m}^3/\text{ha}$$

d) If in the case of example »c» the mortality is estimated to be 5 m³/ha, the forecast volume after the 10-year period is (16):

$$V = (1.1328)^2 \times 200 - 1.1328 \times 5 = 251.0 \text{ m}^3/\text{ha}$$

The total forecast increment is (5):

$$I = 251.0 - 200 + 5 = 56.0 \text{ m}^3/\text{ha}$$

The forecast net increment is (8):

$$I_N = 251.0 - 200 = 56.0 - 5 = 51.0 \text{ m}^3/\text{ha}.$$

Increment Functions

The purpose in this part of the paper is to survey the calculation technique and material for increment forecast, to test and develop the technique on the basis of the available yield data and sample plots measured in connection with the project. The findings of the work have already been published in part (KUUSELA and KILKKI 1963).

The volume increment of stands described by statistical classes can be considered as the dependent variable, which is correlated with other stand characteristics as independent variables. Because the measuring of increment is much more laborious and expensive than the measuring of many other characteristics, the dependency or regression of the increment on the other characteristics can be extremely useful in presenting the measured and forecast increment. In principle this is the method developed by PETTERSON (1955) for constructing yield tables (E.g., FRIES 1964). The stand characteristics such as age, height, basal area, number of stems, etc., at the beginning of the calculation period are taken as independent variables with the increment of different characteristics as the dependent variable.

In the case of increment and drain forecast for a large forest area the growing conditions during the forecast period are not known exactly in advance. The mean stand from numerous individual stands is the calculation unit and the actual treatment of stands may be quite different from the treatment presupposed as a basis for the forecast. Consequently, the regression method of yield table investigations can hardly be used as such in cutting budgets.

It shall be noted, too, that the regression of the dependent variable on the independent variables is more statistical than causal (PETTERSON 1955, p. 27). The interdependence of the variables does not necessarily expound the phenomenon of growing. The regression equation is primarily an auxiliary mechanism for calculating a characteristic on basis of other characteristics.

General Suitability of Stock Characteristics as Independent Variables

In an increment-drain forecast for a large forest area the total growing stock is divided into classes which can be termed the calculation units of the procedure.

These classes are statistical strata in the measurement and calculation technique of a forest inventory and the results of an inventory are also presented according to the same strata. Thus the mensurational characteristics of a class are the means of numerous stand characteristics which are measured in the field work of an inventory. Furthermore, these same characteristics develop during the forecast period due to the growth, cuttings and other treatments. In a large forest area the treatments often vary a great deal and capriciously. Because of these facts the stock characteristics which can be used as independent variables in an increment-drain forecast for a large forest area are hardly the same as those which can be used in constructing yield tables.

If the volume increment is the object of a forecast, the volume of the growing stock seems to constitute a necessary independent variable (e.g., KUUSELA and KILKKI 1963). The growing-stock volume is the »capital» which produces the volume increment and without volume there would be no possibility for drain and no production of wood even on best sites. The volume is an indispensable characteristic in the results of forest inventories too. It is estimated and needed for all sub-groups of the growing stock and consequently it is available for forecast purposes after any inventory. The volume is the most important characteristic in planning the sustained and progressive yield. Maintaining future production presupposes a desirable amount of volume in the forest and consequently the probable volume at the end of the forecast period is of great interest for many other purposes, too, than just for the increment forecast.

Age seems to be the most important characteristic determining the capability of the trees to grow and thus increase their volume. It is often present in the results of forest inventories, e.g., the growing stock is usually presented by age classes. However, the importance of age varies greatly in different forest conditions. In Finland and other North-European countries where the stands are more or less even aged and where the current silvicultural treatments increase their even-agedness, the age is a precise characteristic. It is easily measurable in stands dominated by conifers, which in North-European countries comprise about 80 % of the forests. The age can be readily used for forecast purposes because it increases by calender years in even-aged stands regardless of the kind of cutting.

The effect of site quality on the increment is obvious. Fortunately the combination of age and volume of a stand is a function of the site and determines the amount of the increment within a wide range of site quality. It will be noted, too, that most of the current methods for estimating site quality require the stand age, and if the site is used as an independent variable for increment forecast purposes, the age is indispensable. The estimation of the site quality and its numerical presentation seem to be very difficult problems and it would be a fortunate situation if the increment forecast could be accomplished without site.

The age is not very useful in conditions where the stands consist of numerous

species, of broad-leaved species and of trees of different ages. It is difficult to estimate and its development during a forecast period is indefinite. On the other hand, if age is omitted as an independent variable, the site seems to become indispensible in increment forecast and the estimation of site quality in turn needs age.

In the case of the basal area increment as the dependent variable, the basal area is a good independent variable. Obviously it can be used in connection with the volume increment, too, but for this purpose the volume itself is more natural.

The height and diameter can be used for finding the height and diameter increment. In the conditions where most of the stands are under silviculturally definite treatment they can be used as variables determining the volume increment, too. The development of the height and diameter can be markedly affected by different kinds of cuttings and at present they seem to be of little use for increment forecast in large forest areas.

For volume increment as the dependent variable, the tree species or species groups, age and volume seem to be the most suitable independent characteristics. However, a great change in site and climatic conditions is of importance and in order to get good local results the regression equations obviously should be calculated by broad site classes and climatic regions.

Usable Functions

The increment as the dependent variable can be expressed either in volume increment (i) or as a percentage (p_i). If the volume of the growing stock is v and the annual increment for it is i, the annual percentage is

$$p_i = 100 \frac{i}{v}$$

If the volume at the beginning of a measurement period is v and at the end of a period of n years without drain V, the percentage is

$$1.0p_i^n = \frac{V}{v}$$

(For further details about percentage and its calculation, see the earlier section entitled »Theory and Basic Concepts . . .»)

In a paper prepared as a part of this project (KUUSELA and KILKKI 1963) the possibilities of using an increment percentage function are analysed. The most useful function found in the paper is

$$\log p_i \text{ or } \log (1.0\, p_i^n - 1) = a + b \log t + c\, v$$

where t is the age in years. Mean height (h_g), mean diameter (d_g) and site index (B) can be used as additional independent variables but age and volume determine most of the increment. In the case of $1.0p_i^n - 1$ as the dependent variable, the average volume during the period $(v + V)/2$ is used as independent variable.

There is no difference in principle between using either increment percentage or increment in volume measure because the percentage function presented above

$$p_i = a\, t^b\, 10^{cv}$$

can be expressed in the form

$$i = a\, t^b\, 10^{cv}\, \frac{v}{100}$$

However, some functions for the volume increment have been tested during the project. The best of them are

$$\log i = a + b \log t + c \log v$$

$$\log i = a + b \log t + cv$$

but they do not follow the development of the annual increment as well as the percentage function.

Among others, the equation used by VUOKILA (1960)

$$i = a\, h_{dom} + b\, h_{dom}^2 + c\, g$$

where h_{dom} is the dominant height and g the basal area, both characteristics taken at the beginning of the calculation period, was also tested. This equation gave no better results than the percentage equation.

Material for Calculating Increment Percentage Functions

Yield Tables

In a regression equation of the increment percentage function either the annual increment percentage or the percentage part of the compound interest factor can be used as the independent factor. In the latter case the function can be calculated from any current yield table which gives the periodic development of the growing stock volume and the periodic drain. As an example, the equation

$$y = 5.72291 - 1.20726\, x_1 - 0.00142\, x_2$$

where

$$y = \log 1000\, (1.0p_i^5 - 1)$$

$$x_1 = \log t$$

$$x_2 = (v + V)/2$$

was calculated from the variable density yield table for pine published by NYYSSÖNEN (1958). In spite of the range in site quality and the growing stock volume,

the multiple correlation coefficient is 0.9832 and the error of the estimate (the standard deviation of the estimate on the regression) is 19 % of the standard deviation of y. The equation can be used in the increment-drain forecasts as described in the papers published by KUUSELA and NYYSSÖNEN (1962) and by KUUSELA and KILKKI (1963).

Yield tables of another type are published by NILSSON (1961). They give the volume of the standing stock, annual volume increment (all volumes in these tables are excl. bark) and increment percentage of conifer stands by age, site and density classes for different increment (climatic) regions and the tables are calculated on the basis of the measurements carried out in the Swedish National Forest Inventories. In the following are presented the regression equations separately for regions I, II and III (the three northern regions) and a common equation for all of these regions I—III:

$$\text{I} \quad y = 189.8883 - 0.6946\, x_1 - 0.0767\, x_2$$
$$R = 0.9898 \qquad 100\, s_{y \cdot 12}/s_y = 14.6\ \%$$
$$\text{II} \quad y = 195.7827 - 0.7290\, x_1 - 0.0626\, x_2$$
$$R = 0.9899 \qquad 100\, s_{y \cdot 12}/s_y = 14.4\ \%$$
$$\text{III} \quad y = 193.8258 - 0.7092\, x_1 - 0.0642\, x_2$$
$$R = 0.9946 \qquad 100\, s_{y \cdot 12}/s_y = 10.5\ \%$$
$$\text{I—III} \quad y = 193.7930 - 0.7170\, x_1 - 0.0632\, x_2$$
$$R = 0.9904 \qquad 100\, s_{y \cdot 12}/s_y = 13.8\ \%$$

The variables used in the equations and other symbols are:

$y = 100 \log p_i$
$x_1 = 100 \log t$
$x_2 = V$
R = multiple correlation coefficient
s_y = standard deviation of y
$s_{y \cdot 12}$ = error of estimate.

The site class was also used as a third independent variable but it has no marked effect on the percentages. However, an improving site seems to increase slightly the increment percentage in the conditions where age and volume are constant but the effect is possibly confused by the mensurational errors.

The increment for three stands is calculated by the four equations given above and presented in Table 1. Although the three regions lie between the latitudes of 69° and 60°, the common regression equation for all regions overestimates the increment for the northernmost region only by 4—5 % and underestimates the increment for the southernmost region by 3 %. However, the climatic increment region (»climatic site») seems to have an effect on the increment percentage which is not revealed by the combination of age and volume. The effect is not

Table 1. Increment in m³/ha calculated by equations for the Swedish increment regions I, II and III.

Taulukko 1. Kasvu m³/ha laskettuna Ruotsin kasvuvyöhykkeiden I, II ja III yhtälöillä.

age, years — *ikä, vuosia* volume, m³/ha — *kuutiomäärä, m³/ha*	50 112	70 171	90 207
equation — *yhtälö*			
I	4.81	5.24	5.00
II	4.99	5.48	5.25
III	5.14	5.66	5.44
I—III	4.99	5.50	5.27
Proportional increment for regions I, II and III calculated by equation I—III. Increment from the above is 100. *Suhteellinen kasvu alueilla I, II ja III laskettuna yhtälöllä I—III. Taulukon yläosan kasvu on 100.*			
I	103.7	105.0	105.4
II	100.0	100.4	100.4
III	97.1	97.2	96.9

very great but in an accurate regression equation the »climatic site» should be as an independent variable or the equations should be calculated by suitable climatic regions.

In Fig. 6 is illustrated how the curves calculated by equation III follow the table percentages. There is conspicuous nonconformity only in the case of percentages in the classes of 10-year-old stands. However, the Swedish method for estimating the increment of youngest stands may underestimate it. If this is the case and the equation were calculated without the first percentages, the conformity of the table values and curves would be almost perfect. As stated earlier, the combination of age and volume determines very closely the increment percentage within a reasonable range of site and climate.

Inventory Sample Plots

A direct way of calculating increment percentage functions for forecast purposes is to measure sample plots in the field work of forest inventories, estimate the increment percentage for each sample plot stand and use the plot data for functions. This way was tried using sample plots which were measured as a part of the field training of the Institute of Forest Mensuration and Management of the University in Helsinki. These plots (Table 2) were 1/6 — 1/4 hectare in size

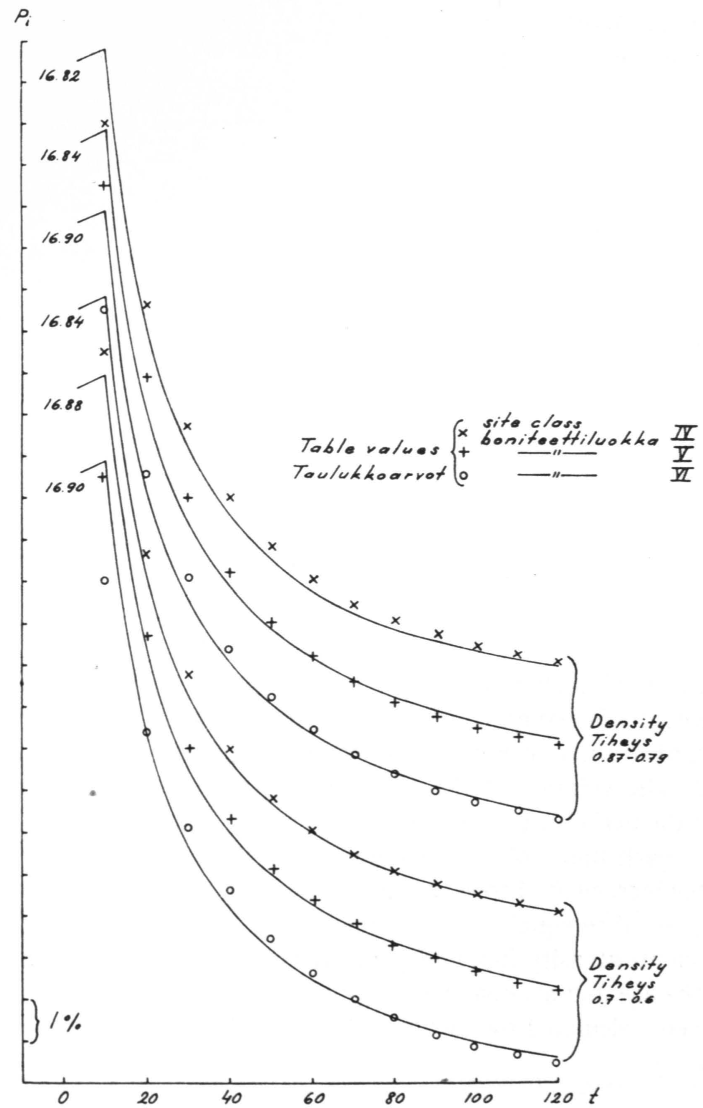

Fig. 6. Increment percentage curves for the Swedish increment region III calculated by a common equation $\log p_i = a + b \log t + c v$

Kuva 6. Yhteisellä yhtälöllä $\log p_i = a + b \log t + c v$ lasketut kasvuprosenttikäyrät Ruotsin III kasvuvyöhykkeelle.

and they are a subjective sample representing the principal age classes and development stages on different sites of the forests in the State Forest District of Evo in South Finland. The plots were measured in 1959—60.

Table 2. Age-class distribution of the stands measured in Evo District.

Taulukko 2. Evon hoitoalueessa mitattujen koealojen jakaantuminen ikäluokkiin.

Age class, *Ikäluokka* years *vuosia*	Number of sample plots dominated by *Koealojen lukumäärä, joissa vallitsevana puulajina on*	
	pine *mänty*	spruce *kuusi*
10	2	—
30	4	4
50	5	6
70	8	7
90	17	20
110	16	12
130	3	2
150	—	1
170	1	—
Total *Yhteensä*	56	52

The increment of each stand was measured by the increment bore and the height increment was estimated with binoculars. The total number of the stands is 108 and in 61 of these there has been cutting drain during the 5-year measurement period. The volumes of the standing stock, drain, standing trees at the beginning of the period and of the drain trees at the beginning of the period were calculated for each stand (all volumes are excl. bark). From experience gained by estimating the increment of trees marked for cutting, the increment percentage of drain was assumed to equal the percentage of the standing stock.

The increment-intensity index (dependent variable) of a 5-year measurement period and the age and average volume (independent variables) in the middle of the period were calculated for each stand. The variables used in regression equations are:

$$y = 100 \log_{1000} [(1.0p_i^{2.5} - 1)]$$
$$x_1 = 100 \log t$$
$$x_2 = (v + V)/2$$

The equation for the stands dominated by pine is

$$y = 426.92 - 1.1674\, x_1 - 0.1518\, x_2$$
$$R = 0.9338 \qquad 100\, s_{y\,.\,12}/s_y = 36.4\ \%$$
$$t_b = 14.77 \qquad t_c = 8.48 \qquad t_{0{\cdot}001} = 3.50$$

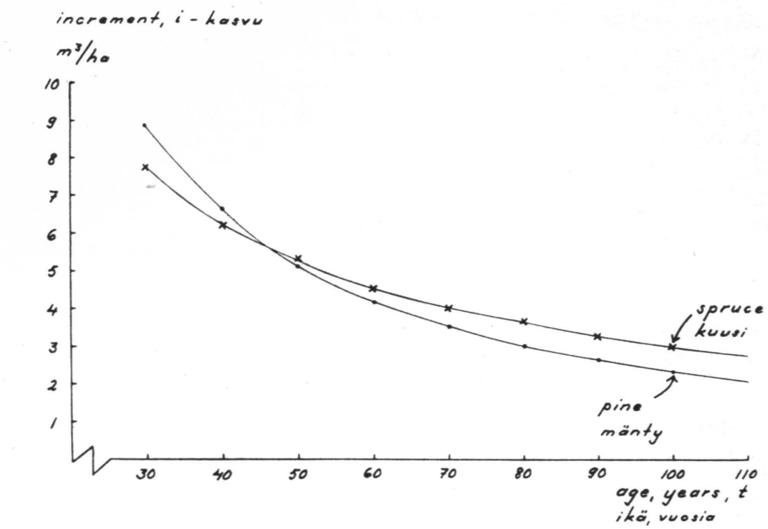

Fig. 7. The increment of the pine and spruce stands of Evo District when the stand volume is constant ($v = 100$ m³/ha).

Kuva 7. Evon hoitoalueen männiköiden ja kuusikoiden kasvu kun puuston kuutiomäärä on vakio ($v = 100$ *m³/ha*).

The equation for the stands dominated by spruce is

$$y = 368.58 - 0.8209\, x_1 - 0.1470\, x_2$$
$$R = 0.9029 \qquad 100\, s_{y\,.\,12}/s_y = 36.7\ \%$$
$$t_b = 8.74 \qquad t_c = 6.17 \qquad t_{0{\cdot}001} = 3.50$$

The common equation for stands dominated by pine and spruce is

$$y = 398.96 - 1.0146\, x_1 - 0.1340\, x_2$$
$$R = 0.9023 \qquad 100\, s_{y\,.\,12}/s_y = 43.4\ \%$$
$$t_b = 15.46 \qquad t_c = 8.67 \qquad t_{0{\cdot}001} = 3.40$$

The multiple correlation coefficient and the amount of explained variation are not as great as in the case of yield table values, which is quite natural because the yield table values are adjusted. The regression coefficients are very significant in all cases. The difference between the regression coefficients of age in the pine equation and spruce equation is significant at the probability level of 0.05.

In a small forest area it seems to be possible to use a common increment percentage equation for stands dominated by pine and spruce but in large areas the result would be more accurate if the equations were calculated by tree species. In young stands the increment percentage of pine is greater than the percentage of spruce but the percentage of spruce decreases less with increasing age (Fig. 7).

Table 3. Age-class distribution of the sample plots measured in the Meltaus District.
Taulukko 3. Meltauksen hoitoalueessa mitattujen koealametsiköiden jakaantuminen ikäluokkiin.

Age class, years *Ikäluokka, vuosia*	70	90	110	130	150	170	Total *Yhteensä*
Number of plots *Koealoja kpl*	1	10	24	15	—	2	52

Further material consisting of 52 sample plots (Table 3) was measured in the State Forest District of Meltaus in North Finland with a purpose of investigating the possibilities of estimating increment, past cut and mortality by systematically located inventory plots of a size of about 1/10 of a hectare (see the section entitled »Mortality in Connection . . .»). The method of estimating the increment was the same as with the plots measured in Evo District (Table 2).

The stands were dominated by pine and their age was comparatively high. They were either in a natural state or cut by selective thinning. The regression equation of these stands is (variables are described earlier in this chapter)

$$y = 522.76 - 1.6228\, x_1 - 0.2773\, x_2$$
$$R = 0.6789 \qquad 100\, s_{y\,.\,12}/s_y = 74.9\ \%$$
$$t_b = 5.13 \qquad t_c = 3.73 \qquad t_{0\cdot 001} = 3.51$$

The multiple regression coefficient and the amount of explained variation are much smaller than in the case of sample plots measured in South Finland. This is mainly because there are no young stands in the northern sample area and the mensurational errors in the old and slowly-growing stands are proportionally greater than in the southern stands.

In conclusion it can be said that the method developed during the project is usable in the Finnish conditions and it provides a better basis for the increment-drain forecast than the percentage method used so far in which the percentages have been adjusted graphically as a function of age and by two or three density classes. In the regression method a proper attention is paid to the effect of the changing growing stock volume on the increment percentage.

Basal Area — Height Method

In a basal area-height method (the two-way method of SPURR) the increments of basal area and mean height are measured and forecasted separately. The volume at the beginning and at the end of the measurement or forecast period is calculated as a product of basal area, mean height and form factor and the volume increment is the difference of the two volumes.

The method is expected to have following advantages:

1. The basal area and the mean height are easily measurable with a relascope sample plot. The basal area is the number of unit trees and the mean height is the arithmetic mean of the unit trees which equals the mean height weighted by the basal area in the ordinary stock.
2. The relascope stock can be economically measured and analysed because the number of unit trees is directly proportional to their contribution to the basal area.
3. The components of the volume increment (the basal area and height increment and the change of tree form) can be estimated separately.
4. The total stem volume and saw timber volume are more or less directly dependent on the basal area and mean diameter (or mean height).

Sample Plots, Measurement and Calculation Technique Used in the Experiment

For the experiment 27 sample plots were measured in pine stands of the State Forest District of Nikkarila in South Finland in 1962. Sample plots were measured by the relascope technique and the main characteristics of these stands are presented in Table 4.

The increment of basal area during a 5-year period was measured by boring the radial increment at breast height and estimating the height increment with the binoculars. The stumps of those trees cut during the increment measurement period were measured and the increment percentage of the cut trees is supposed to equal the increment percentage of existing trees.

The age ($t_{1.3}$) of each stand is the number of annual rings at breast height (*DBH*-age). The site index (*B*) is calculated by using the mean increment of dominant height based on unthinned pine stands (KUUSELA and KILKKI 1963).

Table 4. Sample plots measured for an experiment with basal area — height method.
Taulukko 4. Pohjapinta-ala-keskipituusmenetelmän kokeilua varten mitatut koealat.

Existing stock *Mittaushetken puusto*						Drain during the last 5 years *Poistuma 5 viimeksi kuluneen vuoden aikana*		
DBH-age years *d1.3-ikä vuosia*	Site-class *Boniteetti-luokka*	*N*	*G*	$\bar{h}_g$	*V*	*N*	*G*	*V*
14	13	3666	12	6.6	43			
19	11	703	6	8.5	26			
23	12	1624	13	9.5	68	127	0.4	1.5
24	13	1643	18	11.4	112	127	0.4	1.5
25	12	1199	13	10.5	72			
25	14	740	15	13.5	102			
38	8	998	12	10.9	69			
40	12	950	28	16.9	246	44	1.2	10.3
45	9	1332	17	12.5	109			
47	10	929	19	15.1	141	1183	7.5	35.6
49	9	1759	17	11.9	100			
51	9	496	12	16.2	97	730	4.4	20.8
54	11	790	24	18.6	228			
58	10	470	15	17.9	133			
59	10	1064	18	17.8	236			
72	7	348	11	15.7	82			
75	9	129	7	20.6	70			
75	7	100	5	18.2	45			
76	10	383	16	20.7	157			
78	9	205	11	20.4	109			
78	9	1182	28	18.7	248			
80	9	229	15	20.6	147			
88	8	777	24	18.8	213			
89	11	1084	44	22.5	465			
104	12	844	50	25.8	582			
129	8	154	12	22.1	124			
131	12	96	14	28.7	180	79	6.5	77.1

The volume, including bark, of the existing stock is calculated from the Finnish volume tables compiled by Ilvessalo (1948). In each stand the volume of saw timber and the saw timber percentage (P_{st}) are estimated. The stand characteristics at the beginning of the measurement period are needed for the increment functions. The necessary calculations were accomplished by regression equations. The method and equations are presented here. It may be mentioned that a number of other equations were calculated also, but those presented here were found to be most useful for these sample plots.

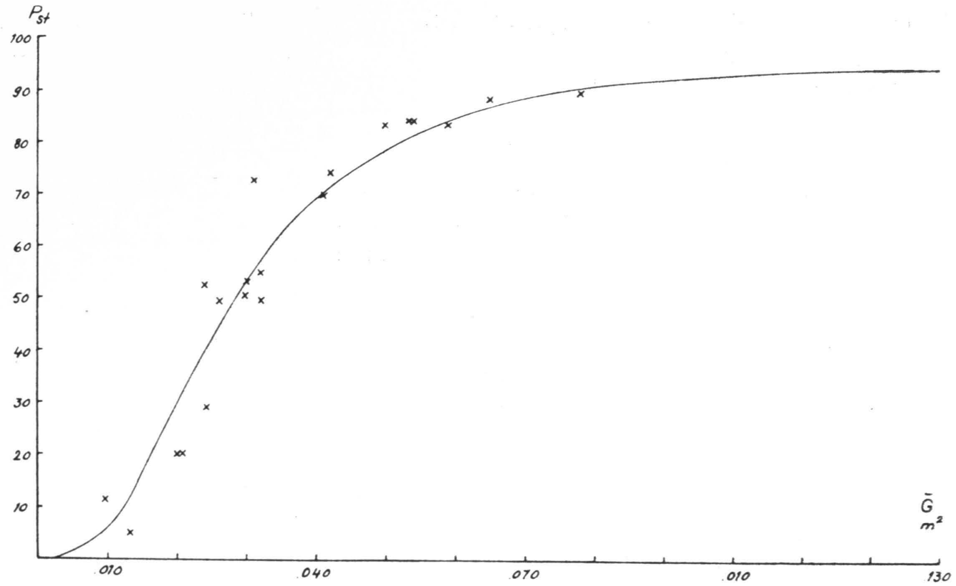

Fig. 8. Regression curve of the saw timber percentage (P_{st}) against mean basal area ($\bar{G}$).
Kuva 8. Sahapuuprosentin (P_{st}) regression kuvaaja keskipohjapinta-alaan ($\bar{G}$) nähden.

The relationship between the number of stems per hectare (*N*), basal area (m^3/ha) including bark (*G*) and mean basal area ($\bar{g}$) is

$$N = \frac{G}{\bar{g}} \tag{1}$$

The form factor (F) can be calculated by the equation

$$1000\,F = 573.9204 - 0.4669\,\bar{h}_g \tag{2}$$

where $\bar{h}_g$ (in decimeters) is the arithmetic mean height of relascope trees (or mean height weighted by basal area). The correlation coefficient is — 0.8723, standard deviation 5.77 % and error of estimate 2.87 % of the mean. A little better estimate of form factor could be calculated by the equation

$$F = a + b\,\bar{h}_g + c\,B$$

with multiple correlation coefficient 0.9014 and error of estimate 2.60 %.

When the form factor is known, the volume, incl. bark, of a stand (*V*) is calculated by the formula

$$V = G\,\bar{h}_g\,F \tag{3}$$

The percentage of saw timber volume (P_{st}) is mainly a function of mean diameter or mean basal area. In this connection the mean basal area ($\bar{g}$) is used as independent variable. The development of the saw-timber percentage is typically an S-curve or a probit function (JEFFERS, 1960). In these sample plot stands the maximum percentage is about 95. The regression equation is of the form

$$\text{probit of } P_{st} = a + b \log \bar{g} \qquad (4)$$

The correlation coefficient is + 0.9642, the standard deviation 18.58 % and the error of estimate 5.06 % of the mean. The saw-timber percentage can be estimated from the graph calculated by the equation (4) and presented in Fig. 8.

Because in temporary sample plots only the increment of diameter excluding bark can be measured, the following equation is needed for calculating the basal area, incl. bark, at the beginning of the measurement period:

$$\bar{g} = 2.8216 + 1.2277\, \bar{g}_{eb} \qquad (5)$$

where $\bar{g}$ is the mean basal area incl. bark and $\bar{g}_{eb}$ the mean basal area excl. bark, both in cm². The regression coefficient is 0.9996, standard deviation 85.8 % and error of estimate 2.3 % of the mean.

For calculating the volume of cut trees on basis of the stumps the following equations are needed:

$$\bar{g} = -22.0211 + 0.6715\, \bar{g}_s \qquad (6)$$

where $\bar{g}_s$ is the mean basal area at stump height in cm² (correlation coefficient is + 0.9983, standard deviation 85.8 % and error of estimate 5.1 % of the mean), and

$$\log \bar{h}_g = 123.9644 + 0.3991 \log \bar{g} \qquad (7)$$

where $\bar{h}_g$ is in decimeters (correlation coefficient is + 0.9584, standard deviation 6.9 % and error of estimate 2.0 % of the mean).

Equations for Increment Forecast

The increment is estimated by regression equations. The dependent variables in these equations are:

$$Y_g = 100 \log [10\,000\,(1.0\, p_g^5 - 1)]$$

$$Y_{\bar{h}g} = 100 \log [10\,000\,(1.0\, p_{\bar{h}g}^5 - 1)]$$

The compound interest factors are calculated by the formulas:

$$1.0\, p_g^5 = \frac{G_E}{G_{E,-5}}$$

$$1.0\, p_{\bar{h}g}^5 = \frac{\bar{h}_{gE}}{\bar{h}_{gE,-5}}$$

Table 5. Coefficients of correlation between the variables

Taulukko 5. Muuttujien väliset korrelaatiokertoimet

	Y_g	Y_h	t	v	g	$\bar{d}_g$	$\bar{h}_g$	B
Y_g	1.000	+0.829	−0.893	−0.676	−0.580	−0.770	−0.858	+0.335
Y_h	+0.829	1.000	−0.922	−0.547	−0.396	−0.832	−0.906	+0.372

Table 6. Regression equations of dependent variables Y_g and Y_h.

Taulukko 6. Regressioyhtälöt riippuvien muuttujien Y_g ja Y_h laskemiseksi.

N:o	Constant *Vakio*	Regression coefficients of *Regressiokertoimet*					R	$100 \frac{S_{y\,.\,123\,\ldots}}{S_y}$
		t	g	$\bar{d}_g$	$\bar{h}_g$	B		
Equations for Y_g — *Y_g:n yhtälöille*								
I	+ 482.0289	− 0.9094	− 0.9257				0.938	36.1
II	+ 463.4821	− 0.7674	− 1.0040	− 0.4681		+ 0.4836	0.940	37.4
Equations for Y_h — *Y_h:n yhtälöille*								
III	+ 358.0055				− 4.7545		0.906	43.3
IV	+ 357.7500		+ 0.0662		− 4.8120		0.906	44.1
V	+ 325.6281		− 0.1762		− 4.3639	+ 2.8942	0.921	41.4
VI	+ 419.0120	− 0.6235			− 1.8775		0.932	37.7
VII	+ 509.1341	− 1.1539	+ 0.0585		+ 0.2428	− 3.3664	0.936	38.3

where G_E and $\bar{h}_{g_E}$ are basal area and mean height of the existing trees at the time of measurement and $G_{E,-5}$ and $\bar{h}_{g_{E,-5}}$ the characteristics of the same trees 5 years earlier.

In analysis the following characteristics were found to have value as independent variables:

- t = 100 log $t_{1.3}$ where $t_{1.3}$ is the breast-height age at the middle of the calculation period;
- g = (m²/ha) basal area at the beginning of calculation period;
- $\bar{d}_g$ = (cm) the mean diameter weighted by basal area at the beginning of calculation period;
- $\bar{h}_g$ = (m) the mean height weighted by basal area at the beginning of calculation period;
- B = site index.

The coefficients of correlation between the variables are presented in Table 5 and the calculated regression equations, corresponding correlation and multiple correlation coefficients and the errors of estimate ($s_{y\,.\,123\ldots}$) as percentages of the standard deviation (s_y) in Table 6.

The regression equations can be used in forecasting the increment of a stand or a group of stands if the needed independent variables are known. With basal area equation I and with mean height equation VI in Table 6 are obviously the most useful. For practical calculations the compound interest factor or the increment itself can be presented in tables as a function of age and basal area and mean height. The graph in Fig. 8 is used for estimating the increment of saw-timber volume.

An Example

The measured characteristics of a pine stock are:

breast-height age	71 years
basal area	27.2 m²/ha
mean height	18.8 m
number of stems	950 per hectare
mean basal area	0.0286 m²/ha

Using equations (2) and (3) and the graph in Fig. 8 the present form factor, volume, sawtimber percentage and saw-timber volume are:

$$F = 0.56514$$
$$V = 289.0 \text{ m}^3/\text{ha}$$
$$P_{st} = 50$$
$$\text{Saw-timber volume} = 144.5 \text{ m}^3/\text{ha}$$

Using equations I and VI from Table 6, the compound interest factors are:

$$1.0\,p_g^5 = 1.07435$$
$$1.0\,p_{\bar{h}_g}^5 = 1.04715$$

The basal area and mean height after the 5-year forecast period are:

$$1.07435 \times 27.2 = 29.2 \text{ m}^2/\text{ha}$$
$$1.04715 \times 18.8 = 19.7 \text{ m}$$

Using equations (1), (2), and (3) and the graph from Fig. 8, the other characteristics are:

$$F = 0.56471$$
$$V = 324.8 \text{ m}^3/\text{ha}$$
$$\bar{g} = 0.0307 \text{ m}^2/\text{ha}$$
$$P_{st} = 61$$
$$\text{Saw-timber volume} = 198.1 \text{ m}^3/\text{ha}$$

The increment of total volume during the 5-year period is 35.8 m³/ha and the increase of saw-timber volume 53.6 m³/ha.

Conclusions

The basal area — height method can be used in increment forecast mainly as a standwise procedure. It may be a comparatively rapid method for preparing

temporary yield tables. For management planning purposes in a large forest area it may be too complicated in comparison to the volume increment percentage method.

The regression equations used in the experiment are preliminary. E.g.: Regression of form factor on mean height (2) is obviously curvilinear in stands including a larger range of age.

Estimating Timber Products in Increment-Drain Forecast

Introduction

The yield forecast in forest management consists of the increment forecast and estimate of the allowable cut in cubic measure and timber products. The estimate of timber products can not be more than an approximation because the amounts of timber products in the actual cut are functions of the silvicultural principles applied and of the market conditions, both of which are very changeable.

Main emphasis is usually laid on the saw-timber portion in the allowable cut because it is the most valuable part. The boundary between saw timber and other timber products is the most distinct. On the other hand, the boundary between industrial cordwood (pulp wood and pit props) and fuel wood is very difficult to determine and varies much with the market conditions.

Determination of the boundary between usable wood (saw timber, industrial cordwood and fuel wood) and waste wood is needed in each yield forecast. One may say that the yield forecast is on a sufficient basis from the point of view of management planning if the portions of saw timber and waste wood in the allowable cut can be estimated.

In Finland and the Scandinavian countries the most usual way to estimate the timber products in the allowable cut is the trial marking of those trees which are considered to be mature for cutting at the time of inventory (ILVESSALO 1956; Instruktions . . . 1958; etc.). The trees marked in the field work are divided into principal timber products. This method of trial marking is laborious and costly, and it gives realistic results only if the trial marking is made according to the same principles as those applied to the actual cuttings to be accomplished in the future, which is hardly the case in a large area consisting of forests divided into numerous ownership classes, management units and holdings.

Another way to estimate timber products in the yield forecast is to estimate those characteristics of the current stock which determine the amounts of timber products in the allowable cut. In order to maintain the productivity of the growing stock, each stand should be treated in a certain way and the amounts of the timber products are, like the allowable cut in cubic measures, functions of the current stock and its characteristics.

Thus the main purpose of this investigation is to find out:

— which characteristics of the part of the stock set off by trial marking determine the amounts of the timber products in this part of the stock;

— which characteristics of the current total growing stock determine the amounts of the timber products in the current stock;

— which characteristics of the current stock determine the allowable amounts of timber products in the future cut.

The total procedure of the yield forecast is supposed to have the following steps:

1. The allowable cut is estimated in cubic meters of bole wood by the method described in other sections of this paper.
2. The percentages of the principal timber products in the allowable cut are estimated and the timber products in cubic meters are calculated.
3. The timber products in commercial units of measure are calculated by conversion factors.

The principal timber products used in this investigation are saw-timber (and veneer) logs, paper wood (including pit props and other industrial cordwood), fuel wood and cutting waste. The mensurational specifications of the minimum length in feet and top diameter under bark in inches of the saw-timber logs are:

	pine	spruce
first log	18′ × 6″	18′ × 7″
top logs	16′ × 5″	14′ × 7″

The paper wood of pine and spruce are measured in logs 2 meters in lenght and up to a minimum top diameter of 8 cm under bark and the fuel wood 1 m in length and up to a 4-cm top diameter under bark. The rest of bole is considered as cutting waste.

The main emphasis in the investigation has been on the conifer species but the treatment of birch stands in the sample plots follows the same lines. It may be mentioned too, that the specifications of timber products vary much under different market conditions and those described above are not quite the same as the ones applied at present in Finland.

Material and its Preliminary Treatment

The available yield table and sample plot material made it possible to examine the problem in two phases. The yield tables of the silviculturally well-treated pine, spruce and birch stands in South Finland (NYYSSÖNEN 1956) include the periodic cut in timber products during different rotations on the most important forest site types. The tables provide the basic material for an examination of the way in which the amounts of the timber products are dependent on the characteristics of the well-managed stands and kinds of cutting. In preliminary calculations the amounts of timber products in the yield tables (NYYSSÖNEN 1958) were transformed into timber product percentages.

Table 7. Principal characteristics of sample plot stands measured in Evo and Nikkarila Districts (number of plots in each class).

Taulukko 7. Evon ja Nikkarilan hoitoalueessa mitattujen koealojen tärkeimmät tunnukset (numerot koealojen lukumäärä luokassa).

Classes *Luokat*		Pine dominant *Mänty vallitseva*		Spruce dominant *Kuusi vallitseva*		Broad-l. dominant *Lehtipuu vallitseva*		Total *Yhteensä*	
		Saw timber *Sahapuuta*	Total *Yhteensä*	Saw timber *Sahapuuta*	Total *Yhteensä*	Saw timber *Sahapuuta*	Total *Yhteensä*	Saw timber *Sahapuuta*	Total *Yhteensä*
Site *Kasvupaikka*	Moist mineral *Soistunut kangas*	8	9	22	24	5	9	35	42
	Dry mineral — *Kangas*	12	14	1	1	—	—	13	15
	Swamps — *Suo*	4	8	11	17	1	2	16	27
Age *Ikä*	—40 years, *vuosia*	—	1	1	3	—	2	1	6
	41—80 » »	3	4	4	7	2	5	9	16
	81—120 » »	17	21	24	27	3	3	44	51
	121+ » »	4	5	5	5	1	1	10	11
Cutting *Hakkuu*	Thinning — *Harvennus*	9	14	11	19	4	7	24	40
	Preparatory and shelter-wood c. *Väljennys ja suojuspuuhakkuu*	7	8	18	18	1	2	26	28
	Clear c. *Avohakkuu*	8	9	5	5	1	2	14	16
Volume of total stand *Kokonaiskuutio*	— 50 m³ ha	1	2	—	—	1	1	2	3
	51—100 »	3	7	3	6	—	3	6	16
	101—150 »	4	6	7	11	—	1	11	18
	151—200 »	4	4	7	8	1	2	12	14
	201+ »	12	12	17	17	4	4	33	33
Volume of marked stand *Leimattu kuutio*	—50 m³/ha	8	15	5	13	1	3	14	31
	51—100 »	7	7	17	17	2	5	26	29
	101—150 »	3	3	7	7	2	2	12	12
	151—200 »	2	2	4	4	1	1	7	7
	201+ »	4	4	1	1	—	—	5	5
Total *Yhteensä*		24	31	34	42	6	11	64	84

In order to examine the amounts of timber products of the planned cut under actual forest conditions, 84 sample plots were measured in the State Forest Districts of Evo and Nikkarila in connection with the field training work of Institute of Forest Mensuration and Management. The number and main characteristics of these sample plots are shown in Table 7.

The plots were measured in 1959—61 and they vary from 0.06 to 0.33 hectare in size. The trees scheduled for cutting during the next 10-year management plan period were marked and estimated in timber products.

The forests of these two districts represent a silvicultural level above the average level in South Finland. The volume and amount of saw timber are greater than average. Thus the results are not applicable to all conditions. However, they show differences between the actual and yield table conditions.

The trees marked for cutting in the sample plot stands were divided into timber products and the timber product percentages of each stand were calculated. In Finland there are several tables available for estimating the timber products of standing trees (Aro 1935; Ilvessalo 1956 a; Heiskanen and Tiihonen 1958; etc.) and the results given by them are not quite equal. All the available methods were tested in order to guarantee equal grounds for the estimates of timber products. It turned out that the timber product percentages of a tree are most closely functions of the diameter at breast height, which has been used as independent variable in the tables published by Aro (1935).

Timber Product Percentages as Functions of the Yield Table Stand Characteristics

The timber product percentages of the periodic cut and of the standing stock are very closely dependent on the age and rather closely dependent on the kind of treatment. Especially in young stands the portion of saw timber is greater in the cut of preparatory and shelter-wood treatment than in the cut of thinning. On better site types the saw-timber portion is greater than on poorer sites in the stands of the same age.

In the yield table stands the timber product percentages of the cut are very accurately determined by tree species, site quality, age and treatment as independent variables.

From the yield table data it was found that the saw-timber percentages of the standing stock are very closely functions of the mean height (h_g, weighted by basal area) and mean diameter (d_g, diameter of the tree which is the median of the stand basal area or the mean weighted by basal area) regardless of the site quality and stand age. Thus Figures 9 and 10 can be used for estimating the timber product percentages of stock similar to the yield table stands. In Figures 9 and 10 is also presented the age of pine and spruce at different mean heights and mean

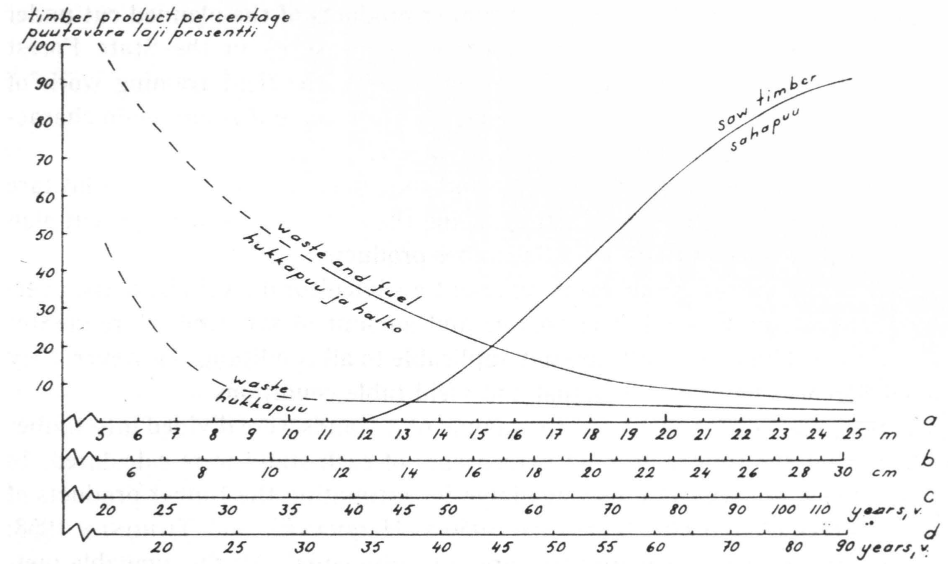

Fig. 9. Development of the timber product percentages in pine stands (calculated from yield tables of NYYSSÖNEN 1958). a = mean height, b = mean diameter, c = age on Vaccinium forest site type, d = age on Myrtillus forest site type.

Kuva 9. Puutavaralajiprosenttien kehittyminen männiköissä (laskettu kasvutaulukoista NYYSSÖNEN *1958). a = keskipituus, b = keskiläpimitta, c = ikä puolukkatyypillä, d = ikä mustikkatyypillä.*

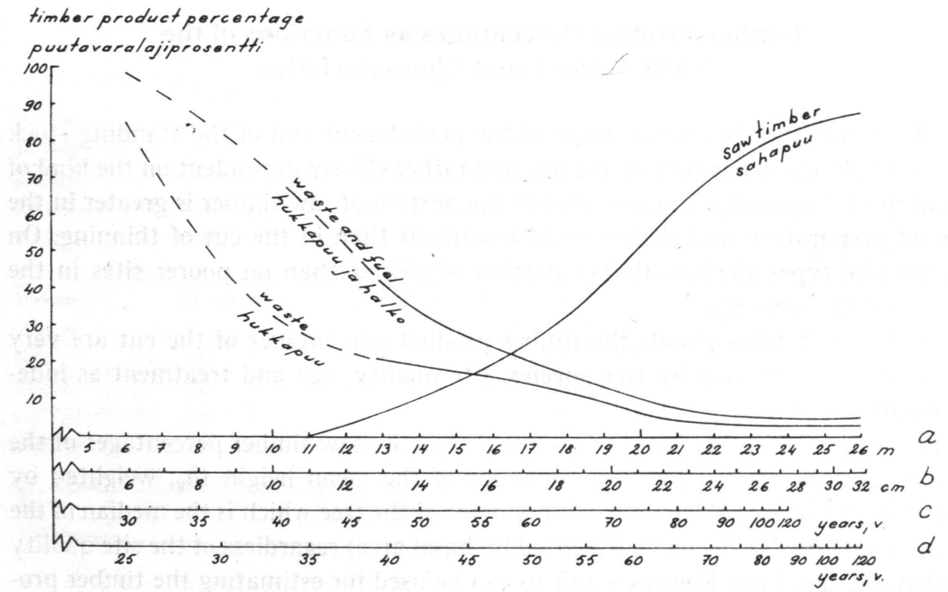

Fig. 10. Development of the timber product percentages in spruce stands (calculated from yield tables of NYYSSÖNEN 1958). a = mean height, b = mean diameter, c = age on Myrtillus forest site type, d = age on Oxalis-Myrtillus forest site type.

Kuva 10. Puutavaralajiprosenttien kehittyminen kuusikoissa (laskettu kasvutaulukoista NYYSSÖNEN *1958). a = keskipituus, b = keskiläpimitta, c = ikä mustikkatyypillä, d = ikä käenkaalimustikkatyypillä.*

diameters on the main forest site types, and the graphs can be used for predicting the development of timber product percentages.

The estimation of timber product percentages in stands similar to yield table stands forms an exception. Most of the current stands are not fully stocked and not under sound silvicultural treatment. However, the future treatment of a forest under management can be assumed to follow the principles of good silviculture. Consequently, the portion of saw-timber product in cut from stands under management should be a function of the kind of treatment and saw-timber product percentage of the standing stock.

Table 8. Saw-timber percentage of the future cut during a 10-year period as a function of the saw timber percentage of the curre nt standing stock and kind of cutting.

Taulukko 8. Hakkuumäärän sahapuuprosentti lähimmän 10 vuoden aikana nykypuuston sahapuuprosentin ja hakkuutavan funktiona.

Saw-timber percentage of standing stock *Pystypuuston sahapuuprosentti*		10	20	30	40	50	60	70	80	90
Saw-timber percentage of thinning cut *Harvennushakkuun sahapuuprosentti*	pine *mänty*	4	8	14	20	28	37	47	59	75
	spruce *kuusi*	4	11	20	28	39	49	60	73	85
Saw-timber percentage of preparatory and shelter-wood cut *Väljennys- ja suojuspuuhakkuun sahapuuprosentti*	pine *mänty*	6	13	21	29	39	49	60	71	84
	spruce *kuusi*	6	15	24	33	44	55	65	77	88

In Table 8 is presented the saw timber percentage of thinning, preparatory and shelter-wood cut during a 10-year period as a function of the saw-timber percentage of the current standing stock in yield table stands. For further consideration it shall be kept in mind that in yield table stands the cutting from below has been used. If the crown thinning is regarded as silviculturally approved, the relationship between the saw-timber percentages of cut and standing stock can be different.

Table 9. Saw-timber percentage of the part of the stock proposed to be cut in pine-dominated stands as a function of mean diameter (_____) or mean height (_) only and as a function of both of these characteristics.

Taulukko 9. Mäntyvaltaisissa metsiköissä hakattavaksi leimatun puuston sahapuuprosentti yksinomaan keskiläpimitan (_____) tai keskipituuden (_) ja kummankin tunnuksen yleisfunktiona.

d_g cm	h_g m																	
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
13	10	13	13	15														
15	17	20	22	24	26	28	30	32										
17	20	27	28	30	32	34	36	38	40	42								
19		32	34	36	38	40	42	44	45	47	49							
21		37	39	41	43	44	46	48	50	52	54	56	58	60				
23			43	45	47	49	51	53	54	57	59	60	62	64	66			
25			47	49	51	53	55	57	59	61	63	65	66	68	70	72		
27					55	57	59	61	62	64	66	68	70	72	74	76	78	
29							62	64	66	68	70	72	74	76	77	79	81	83
31									69	71	73	75	77	79	81	83	85	86
33										74	76	78	79	82	84	86	88	89
35												81	83	85	87	89	90	92
37														87	89	91	93	95
39																94	96	97

Timber Product Percentages of the Allowable Cut in Current Stands

As described earlier, 84 sample plots were measured in South Finland (Table 7) in order to find out how the timber product percentages can be estimated under the prevailing conditions of the current stands. The findings were:

For all practical purposes there is no dependency between the timber product percentages and the stand age, development stage and treatment class because the silvicultural condition and amounts of timber products of the standing stock vary greatly. The main reasons for this are the comparatively high age of the current stands and the indefinite cuttings carried out in them.

The amounts of the timber products in the standing stock and the kind of cutting proposed determine approximately the timber product percentages of the cut.

The most important characteristics of the part of the stock proposed to be cut, which determine the saw timber product percentages of the cut, are the mean diameter and mean height (both weighted by basal area). The regression equations which were used are:

Table 10. Saw-timber percentage of partial stock proposed to be cut in stands dominated by spruce as a function of mean diameter (_____) or mean height (_) only and as a function of the two characteristics.

Taulukko 10. Kuusivaltaisissa metsiköissä hakattavaksi leimatun puuston sahapuuprosentti yksinomaan keskiläpimitan (_____) tai keskipituuden (_) ja kummankin tunnuksen yhteisfunktiona.

d_g cm	h_g m																
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
13	3	6	10	13	16	20											
15	8	12	15	18	22	25	28	31									
17		16	20	23	26	29	33	36	39	43	46						
19		21	24	27	31	34	37	40	44	47	50	53					
21		24	28	31	34	37	41	44	48	51	54	57	61				
23				34	38	41	44	47	51	54	57	61	64				
25						44	47	51	54	57	60	64	67	70	74		
27							50	54	57	60	63	67	70	73	77		
29								56	60	63	66	69	73	76	79	83	
31								59	62	65	68	72	75	78	82	85	
33										68	71	74	77	81	84	87	91
35										70	73	76	80	83	86	90	93
37											75	78	82	85	88	92	95
39													84	87	90	94	97
41													86	89	92	96	98
43															94	97	98

$$\text{saw-timber percentage} = a + b\,h_g$$
$$\text{»} \quad = a + \log d_g$$
$$\text{»} \quad = a + b\,h_g + c \log d_g$$

The correlation coefficient between saw-timber percentage and mean height is in the stands dominated by pine ± 0.900, and in the stands dominated by spruce ± 0.907, the correlation coefficient between percentage and mean diameter in the stands dominated by pine and spruce are correspondingly ± 0.916 and ± 0.896, and the multiple correlation coefficient correspondingly 0.932 and 0.924. In stands dominated by pine the standard deviation is 42.2 % and in the stands dominated by spruce 60.9 % of the mean percentage. The error of estimate calculated by an equation having h_g and d_g as independent variables is correspondingly 15.9 and 23.9 % of the mean percentage.

Tables 9 and 10 are calculated by the regression equations described above and they give the saw-timber percentage of the part of the stock proposed to be cut by trial marking in stands dominated by pine and spruce as functions of the mean height and mean diameter of the partial stock.

Fluctuation of the Increment

Introduction

The annual increment of a growing stock fluctuates markedly in comparison with its average level. The fluctuation is also periodic, i.e., the annual increments which are greater or smaller than the average increment occur in groups or waves. The length of the periodic waves varies and the waves can occur haphazardly or at more or less regular intervals. Because the annual increment may deviate by 30—40 % and the mean of 5—10 years' increments by 10—20 % from the average level, the fluctuation has to be taken into consideration in increment and yield forecasts and in increment investigations in general (Ording 1941; Ilvessalo 1942; Eklund 1944, 1954; Mikola 1950; etc.).

The fluctuation is usually called climatic because it is caused mainly by climatic site factors such as length and temperature of the growing season, rainfall, etc. The increment is dependent on some other factors as well, e.g., the flowering and production of seeds. Only the fluctuation caused by natural site factors such as those mentioned above is under consideration in this case and from it should be eliminated the effect of increasing tree size and age, cuttings, and artificial site improvement.

It is especially important to pay attention to the fluctuation of the increment when the yield forecast is carried out on the basis of the measurements on temporary sample plots in forest inventories and yield studies. The deviation of the increment during the measurement period from the average increment, the average level, and the amount of needed correction will be known if the forecast increment is wanted on the average level, which is the most preferable way to have it.

Only the problem of carrying out the yield forecast on the average level will be under consideration here. However, the forecast of the possible actual increment in the future or increment prognosis on the basis of cyclical development of the climatic factors can also be of interest (Sirén 1961, p. 51).

The fluctuation of increment is usually expressed by increment index series. The average level of increment is set at 100 and the annual measured increment by a percentage of the average. E.g., the annual indexes of measured increment during a 5-year period are 96, 109, 114, 97, 103. If the future increment is predicted on the basis of this periodic increment it is 4 % greater than the average increment.

The problem under consideration may be defined as how to prepare increment index series usable for forecast purposes.

Measurement and Calculation Technique in Preparing Increment Index Series

Increment indexes are usually based on the measured radial increment (thus termed ring indexes) and because the periodic fluctuation of the height increment follows closely the fluctuation of the increment, it is regarded as indicating the fluctuation of the volume increment as well (Mikola 1950, p. 65). The annual radial increment measured by special accurate apparatuses in leveled as a function of age (number of rings). After its culmination (which occurs at a comparatively young age) the radial increment follows closely the curve of the hyperbola; *e.g.*:

$$\frac{1}{y} = a + b\,(x\text{-}k)$$

in which »y» represents the width of the annual ring in year »x» and »k» a certain year in the middle of the period to be studied (Näslund 1942; Eklund 1944).

If all rings from the pith to the surface are wanted for an index series, a more flexible function than described above is needed, e.g.:

$$y = a\,t^b\,e^{-ct}$$

in which y is as above, t represents the number of the ring in order from the pith, a, b, and c are parameters with a positive sign, and e is the base of the natural logarithms (Sirén 1961).

The value of a ring width calculated by a function (regression equation) is set at 100 and the actual width is a percentage of it. The annual percentages form an increment index series.

When the increment cores for index series are collected in connection with a forest inventory, the measurements are from several hundreds or thousands of trees of different sizes and ages. Thus the individual rings for a mean ring are of different ages and at different distances from the pith. This raises the very difficult problem as to what is the weight figure for each individual ring. This far the mean rings have been calculated as arithmetic means.

In practical work there is another problem as to how to join the index series of one inventory to the index series measured in an earlier inventory. It seems hardly solvable in other way than by a graphic and subjective method.

Possible Ways to Prepare and Present Increment Index Series

The climatic factors have a specific effect on the increment of different tree species. Thus the index series must be calculated for each important tree species.

In his paper outlining the possible ways to present statistically the increment index series in connection with Swedish National Forest Inventories, HAGBERG (1959) describes three methods:

1. Index series are based on indicator stands which form a net-work over the country in the same manner as weather stations.
2. The regression of the increment on climatic and other growth factors is analysed and the increment index is calculated by functions with growth factors as independent variables (cf. PATERSON 1956).
3. On the basis of the ring analyses using the cores collected as a systematic sample by forest inventories, the country is divided into increment regions. Inside each region the fluctuation conditions differ from the conditions of other regions and index series are calculated by regions.

The third method or applications of it have been used in Swedish and Finnish national inventories. However, there are no systematic and continuous statistics on increment indexes and only general conclusions have been drawn from the index series concerning how the increment has changed.

In a systematic sample most of the increment cores are from cut stands and the number of cores must be large in order to eliminate the fluctuation caused by cuttings. There should be several hundred — and preferably 1000 to 2000 — cores for each tree species in each increment region. Because of the great number of cores from trees of different sizes and ages, the number of rings measured from a core for the analysis is limited, e.g., 10 to 20 rings (HAGBERG 1959; and in the Fourth Finnish National Forest Inventory). The comparatively short period of years used in repeated inventories makes the tying of a new series of 10 to 20 indexes to a series measured in the earlier inventory very difficult.

The boundaries of the increment regions are based on changing increment conditions. Therefore a system of increment regions found in one inventory may be different from a system suitable in the light of the results obtained in another inventory.

The possibility of estimating the level of increment as a function of climatic and other growth factors (the second method mentioned above) is beyond the scope of this investigation. The use of indicator stands will be discussed in the next chapter.

Indicator Stands

Indicator stands would eliminate some of the difficulties which rise in using systematic samples from forest inventories for increment index series. An example of measurements and calculations of an indicator stand is given in the following.

Sample trees were taken by relascope in a 116-year-old pine stand in natural state. A borer core was taken from each sample tree at breast height, the rings

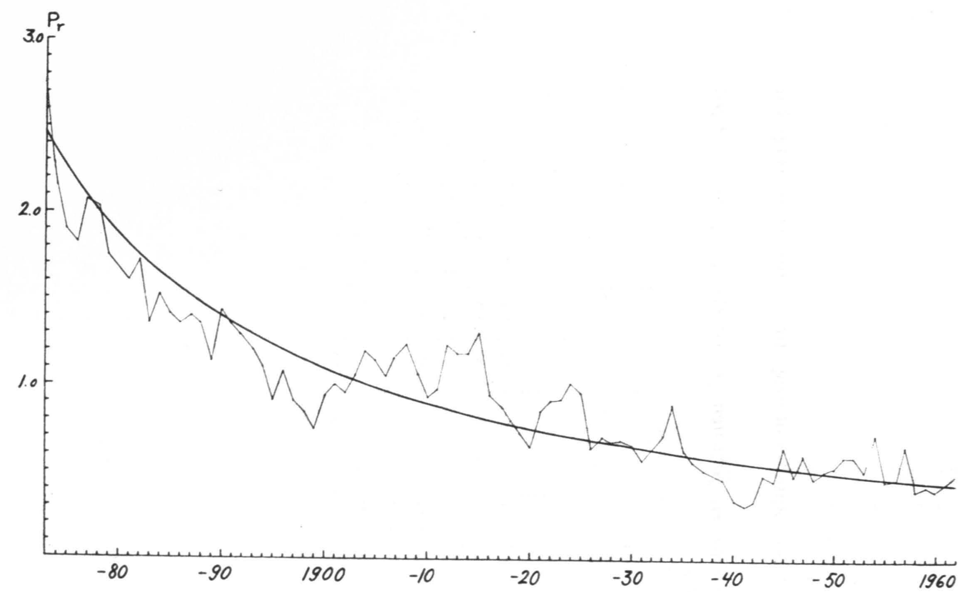

Fig. 11. Regression curve of the annual increment percentages of radius and the observed percentages in an indicator stand.

Kuva 11. Indikaattorimetsikön vuotuisten sädekasvuprosenttien regressiokäyrä ja havaitut kasvuprosentit.

were measured, and the average ring widths were calculated as arithmetic means of the sample tree measurements. Because the trees were taken by relascope, the mean radius and the mean radial increments of the stand are means weighted by basal area.

The annual percentages of the radial increment were used in eliminating the effect of age. In this way it is possible to use a logarithmic function

$$\log p_r = a + b \log t$$

in which p_r = annual radial increment percentage and t = age of a ring or the number of ring in order from the pith.

The annual index is

$$\text{index} = 100 \frac{p'_r}{p_r}$$

in which p'_r = percentage calculated by the regression equation.

The regression curve based on 100 rings and the measured increment percentages for 1873—1962 are presented in Fig. 11 and the increment indexes of the years 1943—1962 in Table 11.

A principal problem in using indicator stands, and in any other way too, is the number of rings needed to find a reliable level for the average increment. In

Table 11. Annual increment index of an indicator stand calculated by different number of rings (n = number of rings for regression equation).

Taulukko 11. Indikaattorimetsikön vuotuinen kasvuindeksi laskettuna eripituisten jaksojen perusteella (n = vuosilustojen lukumäärä regressioyhtälöä laskettaessa).

n \ year *vuosi*	1943	—44	—45	—46	—47	—48	—49	—50	—51	—52	—53	—54	—55	—56	—57	—58	—59	—60	—61	1962	Mean of- *keskiarvo* 1958—62
20	88	81	118	91	113	87	97	100	116	116	99	140	91	93	133	84	89	86	85	105	90
30	94	87	125	97	120	92	102	104	120	120	103	147	94	96	136	85	91	86	96	105	93
40	90	83	121	94	117	91	102	105	121	122	105	151	97	100	143	90	97	93	104	115	100
50	89	83	121	94	118	91	103	106	123	125	107	154	100	103	148	93	100	97	109	120	104
60	89	83	121	94	118	91	102	106	123	124	107	153	99	102	147	93	100	86	108	119	101
70	87	81	118	91	114	88	98	101	117	118	101	145	93	96	137	86	92	89	99	109	95
80	86	80	116	90	112	87	97	99	115	116	99	142	91	94	134	84	90	87	97	106	93
100	88	81	118	92	115	88	99	102	118	119	102	146	94	96	138	87	93	89	100	110	96

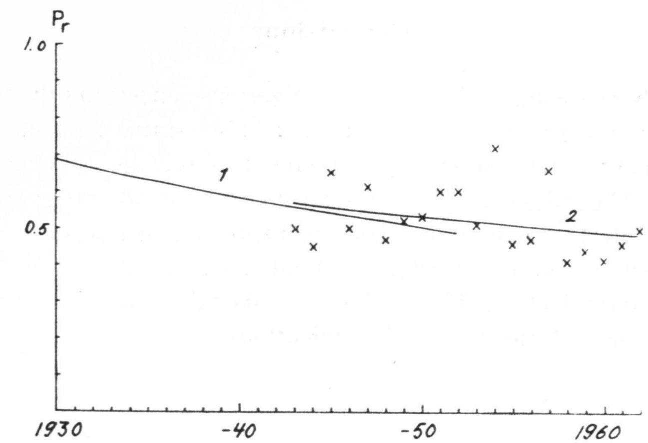

Fig. 12. The problem of tying the regression curve of 90 rings (1) to the curve of 20 rings (2).
Kuva 12. Ongelma yhdistää 90 vuosilustoon perustuva regressiokäyrä (1) 20 vuosiluston perusteella laskettuun regressiokäyrään (2).

Table 11 are presented the annual indexes of 1943—62 based on a different number of the rings giving the average level. The regression curve which gives the average level of the increment can be likened to a lever. Depending on the phase of the fluctuating increment waves where the lever happens to be located, the end of the curve gives indexes very different in size for that period which is most often in question, i.e. the last five years, or 1958—62 in this case.

In Fig. 12 is presented the problem of tying the average level of increment based on a 20-year period (1943—62) to the average level based on a 90-year period (1863—1952). For the same reason as above, the tying can be but a very subjective and vague procedure.

Another problem is the sufficient number of sample trees to be bored in each indicator stand. Thus far, a minimum of 10 trees has generally been considered necessary.

In the following table is an example of how great the standard deviation and standard error can be in a naturally normal indicator stand with 91 rings at breast height:

Period — *Jakso*	1962–58	1957–53	1952–48	1947–43	1942–38
Increment index, mean of 20 trees .... *Kasvuindeksi, 20 puun keskiarvo*	72.8	106.9	116.2	122.9	96.7
s	10.0	20.0	15.2	17.7	21.7
$s_{\bar{z}}$	2.2	4.5	3.4	3.9	4.8

It seems evident that the fluctuation of the increment is highly individual and great in trees even in the uncut naturally normal stands.

Conclusions

Although there are many thorough investigations concerning the fluctuation of the increment, the problem of calculating reliable statistics which present the annual increment compared with the increment in average growing conditions is still unsolved. The indexes calculated so far give an idea of how great the fluctuation can be but the estimates of the accurate magnitude of the fluctuation during a given period are affected by inadequate calculation methods and by numerous random factors. The problem needs additional investigations from the point of view of the practical applications.

Mortality in Connection with the Increment-Drain Forecast

Importance of Mortality

The importance of mortality in connection with the increment-drain forecast depends on intensity of forestry. If large areas fall outside of the regular cuttings and if the dead trees cannot be used as timber products, the mortality and its importance are great. On the other hand, if in an intensive forestry stems of all sizes and even the large-sized dead trees can be used the mortality is of negligible importance.

For example, in 1927 the mortality and the volume of trees left to decay in the forests of Finland were estimated to be 2.55 million m^3, or 6 % of the total drain. In 1938 the estimate of the mortality percentage was 5 %, 4 % in 1948—54, and 2 % in 1955—61. The volume of mortality corresponding with the last percentage is 1 million m^3, excl. bark (SAARI 1934; OSARA . . . 1948; PÖNTYNEN 1962). At the present the mortality is obviously dropping rapidly and considerable amounts of dried-up trees that have been dead for several years are used for many purposes, and even stems and parts of them which have been left in forests of North Finland as logging waste some years ago have been gathered to some extent for fuel and pulp.

In an earlier stage of North European forestry the mortality has been important in timber budgets, and the problem of estimating it has been the object of discussions and experiments. At present its importance is decreasing. In Sweden, for example, the mortality is considered negligibly small. In most cases it is estimated as a lump amount.

Possibilities of Estimating Mortality

The yield tables of fully-dense, naturally-normal stands indicate the mortality under natural conditions (ILVESSALO 1920, 1937). These tables give the mortality as a function of age and forest site type as shown in Tables 12 and 13.

If the rotation is 80—90 years and the age-class distribution even (the forest is fully regulated), the annual volume of mortality is 1.1 % of the growing stock volume in South-Finland's naturally-normal pine stands, 0.9 % in spruce stands, and 1.4 % in birch stands.

Table 12. Annual mortality in naturally-normal pine stands of South Finland (ILVESSALO 1920) expressed as percentage of the growing-stock volume.

Taulukko 12. Etelä-Suomen luonnonnormaalien männiköiden vuotuinen luonnonpoistuma prosenttina elävästä puustosta.

Age, years — *Ikä, vuosia*	15	25	35	45	55	65	75	85	95	105	115	125	135
Myrtillus site type *Mustikkatyyppi*	4.4	2.6	1.8	1.1	0.9	0.8	0.7	0.8	0.6	0.6			
Vaccinium site type *Puolukkatyyppi*	2.6	2.4	2.2	1.7	1.2	0.9	0.8	0.7	0.6	0.5	0.4	0.3	
Calluna site type *Kanervatyyppi*	1.4	1.3	1.2	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6

Table 13. Annual mortality in naturally-normal pine stands of North Finland (ILVESSALO 1937) and in pine stands measured in Meltaus, expressed as percentage of the growing-stock volume.

Taulukko 13. Pohjois-Suomen luonnonnormaalien männiköiden ja Meltauksessa mitattujen männiköiden vuotuinen luonnonpoistuma prosenttina elävästä puustosta.

Age, years — *Ikä, vuosia*	30	50	70	90	110	130	150	170
Empetrum-Vaccinium site type *Variksenmarja-Puolukkatyyppi*	0.53	0.74	0.88	0.96	0.91	0.79	0.69	0.63
Empetrum-Myrtillus site type *Variksenmarja-Mustikkatyyppi*	0.45	0.96	1.16	0.98	0.89	0.82	0.79	0.71
Ericaceae-Cladina site type *Varpu-Jäkälätyyppi*	0.91	1.14	1.53	1.17	0.96	0.84	0.76	0.70
Stands measured in Meltaus *Meltauksen metsiköt*				0.22	0.21	0.30		

Based on the yield tables for the naturally-normal stands and on the permanent sample plots maintained by the Forest Research Institute the lump estimate of the mortality as a percentage of the growing stock volume has been in Finland.

in 1927	0.19 %
» 1938	0.15 »
» 1948—50	0.14 »
» 1955—61	0.08 »

In the sample plot stands measured in the Districts of Evo and Nikkarila (p. 42) the dead trees were also measured. It turned out that in the South Finland the mortality which will decay in the forest is negligibly small.

In connection with the sample plots in the Meltaus District (p. 32) the trees considered to have died during the increment measurement period were tallied separately. The estimate of the total drain (including the cut trees and the trees

dying of natural causes) for the area under survey was 0.81 m³/ha annually and the mortality 0.18 m³/ha annually. The estimate of the annual increment was 1.63 m³/ha and the mortality is 11 % of the increment.

In this particular case the amount of mortality is comparatively great because the area has been outside cutting operations. However, the estimate of the mortality may not be very accurate because there was no objective basis for determining the time during which the trees have died.

Scheme of Cutting Budget for Desirable Growing Stock

Increment Forecast Methods in Sveden and Norway

In many cutting budgets prepared recently in S w e d e n there has been no increment forecast in the proper sense of the word (e.g. HAGBERG and NILSSON 1959; NILSSON 1960). The bulk of the allowable cut estimated for large forest areas comes from old and over-aged stands and therefore the increment has not been considered as having much effect on the amount of the cut in the near future. The allowable cut consists of the stands to be regenerated and of thinning wood estimated by trial marking on the inventory sample plots.

Silvicultural programs with different sizes of regneration areas have been the basis of alternative future cuts. The proposed allowable cut is the alternative cut which has a feasible silvicultural program. The increment as an amount to be compared with the allowable cut has been of small importance, possibly because the actual cut in recent years in Sweden has been smaller than the increment. Long-term cutting budgets and stock-development forecasts have not been judged necessary.

However, increment forecasts have been prepared under conditions in which the area of stands proposed to be regenerated has been so large that the sustained future yield may be endangered. These forecasts have been prepared mainly using tables based on the results of the Swedish National Forest Inventories. These tables give the annual increment in cubic measure, annual increment percentage, and the mean volume of the growing stock for the most important tree species by age, density, and site class in six increment regions (NILSSON 1961). Increment is estimated by age classes from suitable tables. The effect of the improving silviculture on the increment is regarded as being very difficult to estimate. The development of the increment in the old stands is supposed to resemble its development as a function of age in the tables.

The increment of the new stands growing in the regeneration areas is estimated from the same tables which give the increment of the current stock. However, the new stands are assumed to grow better than the current stands. The site index of the new stands based on age and height is supposed to be better than the site index on the current stands in the same locality. For example, in the growing-stock development forecast prepared for the region of Jämtland the increment of the new stands is assumed to follow the table in which the site is a class better than in the table used for the current old stands.

Stock development forecasts like those described briefly above have been used mainly in estimating the maximum regeneration area for a management plan period which does not jeopardize the sustained yield in the future.

In N o r w a y the cutting budgets and the increment forecasts connected with them have been one of the most important tasks in management planning since about 1953 (SEIP 1953; NERSTEN and DELBECK 1961). A key concept in cutting programs has been the greatest sustained cut, termed the »balance line of cut prognosis». It is the greatest possible cut which can be obtained from year to year until the thinnings from the new stands established by the treatment program start to increase the annual cut. This greatest sustained cut has been used also in estimating the value of forests.

In a cutting budget the total growing stock is divided into parts by tree species, site, kind of cutting, and age class. The development of each part of the stock is estimated up to its final cutting and the development of new stands established after final cuttings are predicted to the end of the forecast period.

The current volume and increment of each part of the stock are estimated by forest inventory. The development of a »normal» stand as a function of age is constructed by tree species and site classes on the basis of the yield tables. The development of a normal stand includes the volume of the standing stock and periodic thinnings. The increment forecast for the current stock is usually made under the supposition that the present increment increases 1 % annually in the future until it reaches the increment of a normal stand on the same site. For example, if the increment of the current stock is 70 % of the increment of the normal stock, during the first 10-year forecast period it is on an average 75 %, during the second period 85 %, and at the end of the third period it attains the increment of the normal stock.

The allowable cut from stands under thinnings is $v^2/100$ (v = the volume of the growing stock at the beginning of a period) during the 10-year forecast periods. If in this way the growing stock attains the volume of the normal stock earlier than the annual increment, the allowable cut from this part of the stock is estimated as a matter of judgment. From that moment onward when the volume and increment equal the volume and increment of the normal stock, the forecast is continued in accordance with the normal stand table.

Each part of the stock or group of stands in the forecast procedure is regenerated at the age of prescribed rotation. The age at the time of the final cut may deviate from the prescribed rotation in the case of a growing stock with uneven age-class composition. There has been a rule by which the final cut can be accomplished at an age not more than 10 years under and 20 years over the prescribed rotation.

The forecast development of the seedling stands and new stands established during the procedure is prepared from the normal stand tables. If the density of these stands is not full, their volume and increment are converted by a »zero-percentage» table. For example if 70 % of the area of a seedling stand can be considered fully stocked and 30 % of it is open, the zero-percentage is 30 and the forecast development is prepared by the 30 % table which gives the volume, increment, and cut for the group of stands in question.

The main purpose of the stock-development forecast is to find a regeneration program for the old stands which gives the greatest cut but which does not decrease the growing stock so much that the cut must be decreased before the new stands are mature for thinnings. In addition to the complete method there is a short-cut method for estimating the greatest sustained cut (NERSTEN and DELBECK 1961). The complete procedure has been programed for electronic computors and has been used in calculating the allowable cut for management units of the Norwegian Forest Service.

Increment Forecast Methods in Finland

In Finland the increment forecast in forest management planning was put on a systematic basis in a cutting budget called the »rental cut method» and developed by LIHTONEN (1943). The increment in this cutting budget is estimated by a percentage method introduced by JONSON (1928) and developed by ILVESSALO (e.g., 1942) for the Finnish conditions. For preparing increment forecasts there are tables which give the percentage of the current annual increment estimated by the sample plots of the Finnish National Forest Inventories and presented by dominant tree species, age, and density classes (e.g., ILVESSALO 1948).

In the rental cut method the increment and the allowable cut for two management plan periods of 10 years each is estimated by age or development-stage classes as calculation units. The total growing-stock volume of each class estimated in an forest inventory is divided into two components: the exploitable stock and developable stock (cf. also KUUSELA 1958). The summation of the two is called the initial volume of the growing stock.

The initial volume of the exploitable stock consists of the trees which are proposed to be cut or expected to die as the mortality during the budget period. On an average, these trees will be growing half the number of the years in the whole period. The corresponding increment is calculated by the percentage method and added to the initial volume of the exploitable stock. The sum gives the allowable cut in the calculation unit.

The developable stock consists of the trees which will be growing through the budget period in the forest. Forecast periodic increment added to the initial volume of this part of the stock gives the growing stock at the end of the budget period. This is the initial growing stock for the second period.

The sum of the allowable cuts of the calculation units is the allowable cut for the total forest. On the areas of those age (or development-stage) classes which will be regenerated during the period, there is only the exploitable stock at the beginning of the period and at the end of it there is the volume of the new seedling stands.

The initial volume of the exploitable stock is estimated from the trial marking on the sample plots or from ocular estimates and in accordance with the silvicultural condition of the forest, distribution of the age classes, rate of growth, degree of stocking, amount of wood expected from the forest, etc. The aim is to develop the current growing stock toward a desirable stock and to guarantee a constant or, preferably, a gradually increasing annual cut.

During recent years the cutting possibilities of the forests of Finland have been estimated by a method called stock-development forecast (KUUSELA 1959; HEIKURAINEN, . . . 1960). This is a percentage method and the forecast is based on the volume of the current and desirable growing stock and the annual increment percentage, all characteristics described as functions of age. The calculation procedure covers the period of about a single rotation.

The most recent procedure is called the cutting budget for a desirable growing stock (KUUSELA and NYYSSÖNEN 1962). It is based on Finnish and Scandinavian experience and developed partly in connection with this project. The outlines and the latest stage of its technique is described in the next section.

Basic Data and Principles for a Cutting Budget

The main purpose of a cutting budget in regulated forestry is to work out a cutting program which will develop the current growing stock toward a desirable one. This program gives an allowable drain (including cut and mortality) by stand development or age classes and the distribution of the cut into principal timber products.

The necessary data on the current growing stock collected by an inventory are (KUUSELA and NYYSSÖNEN 1962):

- the average site quality of the forest or those parts of the forest which form calculation units;
- the area of the stands dominated by different species or species groups; (if there is only one major species, this break-down of the total area into sub-areas is not necessary and only one cutting budget is needed).
- the distribution of the stands into age or development classes; (if development class is used as a calculation unit, the age of each class is estimated).
- the volume of the growing stock and the timber-product percentages in each calculation unit; (if timber-product percentages or other necessary characteristics are estimated on the basis of mean height, mean diameter, etc., they are also included in the inventory data).
- regression equations of increment intensity index or increment percentage for each group of stands distinguished on the basis of the dominant species; (for a large area the equations are calculated from the sample plot measurements carried out in the inventory and for small forests the equations based on the National Forest Inventories can be used; special tables calculated by the equations can also be used).
- estimates of the average mortality as a function of age or other appropriate characteristics if the mortality is of importance.

The volume of the desirable stock is estimate from the yield tables and presented as a function of age or stand development classes. The current stock is compared with desirable one and a reasonable intermediate desirable stock at the end of the forecast period is determined.

The estimates of future increment and drain for stands in the thinning stage and older are calculated by increment intensity indexes or tables prepared by the index equations. The forecast development and drain of seedling and sapling stands are estimated better by the yield tables than by the percentage method.

An Example of a Cutting Budget

Various details of the basic principles are most conveniently described in connection with the example presented in Table 14 where there is an increment and drain forecast for a growing stock dominated by pine. Three development-stage classes are included in the procedure and each of them is an example of a different kind of calculation. In Finnish forest management the following stand development classes are used:

- open areas and seed-tree stands
- seedling and sapling stands
- stands in the thinning stage
- stands in the preparatory stage
- mature stands to be regenerated
- shelterwood stands
- low-yielding (residual, etc.) stands

Referring to Table 14, the average age (2), area (3), mean volume excluding bark (4), and saw-timber percentage of the volume (5) have been estimated by development classes in an inventory. The average site is Vaccinium forest site type. In the example there are only the percentage of saw timber, which is the most important timber product, and the waste wood percentage. The mean volume multiplied by the area gives the total volume for each class (6). The summations of the areas and volumes of the classes give the total area and volume of the forest.

The final stock at the end of the forecast period is the intermediate desirable stock at the end of the 10-year forecast period and it is determined from a yield table, part of which is presented below:

Table 14. Scheme of a cutting budget. Stands are dominated by pine and the average site is Vaccinium forest site type. Forecast period is 10 years.

Taulukko 14. Hakkuulaskelman kaavio. Metsiköt ovat mäntyvaltaisia ja kasvavat puolukkatyypillä. Ennustejakso on 10 v.

Development class *Kehitysluokka*	Age, years *Ikä* v.	Area *Pinta-ala*	Initial stock v *Alkupuusto*			Final stock V *Loppupuusto*		Increment intensity index *Kasvuindeksi* $1.0p^5$	$1.0p^5x$ v	V $1.0p^5$	Allowable drain D *Suunnite*		
		ha	m³/ha	Saw timber % *Sahapuu %*	m³	m³/ha	m³		m³	m³	m³	Saw-timber % *Sahapuu %*	Waste-wood % *Hukkapuu %*
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Seedlings .. *Taimisto*	11	35	17	—	595	30	1 050	—	—	—	140	—	80
Thinning stands .... *Harvennusmetsiköt*	52	104	105	13	10 920	145	15 080	1.3326	14 552	11 316	3 236	6	7
Regenerat-able stands *Uudistusmetsiköt*	101	21	180	71	3 780	2	42	1.1584	—	—	4 379	73	4
Total stock *Kokonaispuusto* ..		160	96	26.8	15295	101	16 172				7 755	43.7	6.6

Increment during the period $V + D - v = 16\ 172 + 7\ 755 - 15\ 295 = 8\ 632$
Jakson kasvu » »

Age, years *Ikä, vuosia*	Desirable mean volume, m³/ha *Tavoiteheskikuutio*	Drain, m³/ha *Poistuma*
10	8	1
20	27	4
30	55	14
40	88	
50	119	
60	143	

The seedling stands will be 21 years old at end of the forecast period. The desirable volume is 30 m³/ha (7) and multiplied by the area it gives the desirable growing stock for the class, which is 1050 m³ (8). The drain caused by tending cut and mortality during the forecast period is 4 m³/ha, which is 140 m³ (12) for the total area of this class.

The waste-wood percentage, 80 %, is estimated from the graphs in Fig. 9 on p. 44. Thus the percentage of the usable cord-wood timber is 20 %.

For the thinning stands the desirable mean volume at the end of the forecast period is 145 m³ and the desirable volume on the total area 15 080 m³.

The increment intensity index is calculated by the equation of the stands dominated by pine in the Evo District (p.30):

$$100 \log 1000\,(1.0p^{2.5} - 1) = 426.92 - 1.1674\,(100 \log t) - 0.1518\,v$$

The mean volume during the period is 125 m³. Because the regression equation is calculated for a 5-year period and the forecast period in the example is 10 years in length, the calculation technique described in the section »Increment Intensity Index» is used. The index for a 10-year period is $1.0p^5 = 1.3326$ (9). The allowable drain in this class is 3236 m³ and the forecast increment of the thinning stands during the period is

$$V + D - v = 15\,080 + 3\,236 - 10\,920 = 7\,396 \text{ m}^3$$

and the mean annual increment is 7.1 m³/ha.

The saw-timber percentage of the current thinning stock is 13 %. Using Table 8 and Fig. 9 on p. 44 the allowable saw-timber percentage in the drain is 6 %. The waste-wood percentage is 7 %, which includes the cutting waste and mortality.

The increment intensity index for the regeneratable stands is 1.1584. This stock will be cut during the forecast period and the initial volume is considered to grow 5 years on an average. The product of the initial volume and the increment index is allowable cut. In the same way as in the case of the thinning stands, the current saw-timber percentage is expected to increase to 73 % during the 5-year period. The waste-wood percentage of the allowable cut is 4 %.

On the area of the regeneratable stands the final stock at the end of the period (7, 8) consists of the volume of the new seedling and sapling stands which will be established during the forecast period. Their volume is estimated by the volume table.

The initial stock, final stock, allowable cut, and characteristics of the total forest are summations of the corresponding values of each development class.

If the future drain is determined in advance and an approximate estimate of the final growing stock volume at the end of the period is desired, it can be calculated by formula (16) on p. 20:

$$V = (1.0p^5)^2\, v - 1.0p^5\, D$$

For example, the predetermined drain from the thinning stands is 4 000 m³ and the approximate volume of the growing stock at the end of the period is:

$$V = 1.3326^2 \times 10\,920 - 1.3326 \times 4\,000 = 14\,012 \text{ m}^3,$$

and the final volume per hectare is 135 m³.

In the total allowable drain the saw timber percentage is 43.7. Consequently the saw timber volume is 3 389 m³, excl. bark. On an average this is, in commercial units based on top diameter of saw logs, 81 336 cu.ft.

Proposals

On the basis of the results obtained during this research project some proposals for preparing an increment-drain forecast for a large forest area can be presented:

The increment and the allowable drain (including cut and mortality) is expressed in cubic measure of the actual and total volume of the stem from the ground to the top of the trees. Thus the estimates can be used under any logging and market conditions.

The current total volume of the growing stock at the beginning of the forecast period is estimated by calculation units, i.e. by the stand development or age classes. The desirable volume needed in the continuous production of wood at the end of the forecast period is determined. The allowable drain is a function of the current volume, desirable volume, and the capability of the growing stock to produce increment.

The capability of the growing stock to increase is estimated as a dependent variable determined by a set of independent variables. The increment percentage is a suitable dependent variable, and it seems to be easier to find usable forms of regression equations for the increment percentage than for the increment in cubic volume.

The regression equations of the increment percentage are calculated by stand types dominated by principal tree species or species groups. In a very large forest area they can be calculated by broad site classes and climatic increment regions. There may be possibilities for using climatic index (such as the length of the growing season) as an independent variable in the increment percentage equation.

In the forest conditions of Finland the age and volume of the growing stock are the most efficient independent variables. Possibilities for using indexes of the site quality including the effect of the soil and climate require additional investigations.

In detailed and standwise investigations many other characteristics, e.g., basal area, height, diameter, etc., can be used advantageously. For this purpose and for accomplishing »short-cut» yield tables the mean height-basal area method seems promising.

Data for calculating the increment percentage equations can be measured by sample plots in connection with the forest inventories. The increment and other necessary characteristics are estimated on the plots comprising a representative sample of the forest in question. The percentage equations can be calculated also on the basis of the existing yield data if there is no possibilities to measure inventory sample plots.

Once there are suitable increment percentage equations, the increment and drain forecast for a given growing stock is found on the basis of the same growing stock characteristics which are independent variables in the equations.

The amounts of principal timber products in the allowable drain (saw-timber, pulpwood, fuelwood and wastewood including mortality) for management planning purposes can be estimated most advantageously from the amounts of the timber products in the growing stock. For example, the timber-product percentages of the growing-stock volume are estimated by the development or age classes. The development of these percentages as a function of time is estimated by yield data or by special investigations. These data determine very closely the timber product percentages in the allowable cut from the growing stock classes because only a certain amount of saw timber, pulp-wood, etc. can be cut from each class if the growing stock is to develop towards a desirable condition. The forecast amounts of the timber products in the allowable cut are a general guide and estimate of the cutting possibilities because the actual cut may vary greatly due to the market conditions.

The timber-product percentages of the growing stock and in the part of the stock proposed to be cut are very closely functions of the mean diameter and mean height. Consequently, the estimation of the timber products can also be made on the basis of these characteristics.

The timber products in the allowable cut are estimated by percentages and the estimates in cubic measure are calculated as commercial units by conversion factors.

The mortality can be estimated by development or age classes using average data collected by temporary or, more accurately, by permanent sample plots. The mortality, except in cases caused by large scale windfalls or epidemic diseases and insect damages, is a function of the stand type, development stage, and density. In areas where the bulk of the dead trees of marketable size is collected for economic use, the mortality is of little importance and it can be estimated as a lump amount.

The effect of climatic fluctuations on the increment can be taken into account in two ways: The annual increment indexes, which show the actual annual increment compared with the increment of average climate, are calculated on the basis of the increment-core measurements. The measured increment of the sample plot stands is adjusted by these indexes and the regression equations are calculated by the increment values of the average climate. Another way is to measure increment sample plots continuously year by year and use them all in calculating the equations. Thus the increment given by these equations is on the average level of the period of those years during which the plots have been measured.

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Abbreviations

AFF = Acta forestalia fennica.
MS = Meddelanden från Statens Skogsforskningsinstitut.
MNS = Meddelelser fra det Norske Skogsforsøksvesen.
MTJ = Metsäntutkimuslaitoksen julkaisuja. Communicationes Instituti forestalis Fenniae.
NSkT = Norrlands Skogsvårdsförbunds tidskrift.
ST = Skogsvårdsföreningens tidskrift.

SELOSTE:

KASVUN JA POISTUMAN ENNUSTE SUURELLE METSÄALUEELLE.

Johdanto (ss. 1—16)

Kasvun ja poistuman ennustetta tehtäessä suurelle metsäalueelle on käytetty useita menetelmiä, joista ehkä vanhin on perustunut kasvutaulukoiden tiedoille. Koska kasvutaulukot kuvaavat yleensä vain tietyllä tavalla käsiteltyjä ja täysitiheitä metsiköitä, on niiden lukusarjoja muunnettava silloin, kun kysymyksessä ovat suurten alueiden vaihtelevat metsiköt. Taulukoiden edut tulevat parhaiten esille arvioitaessa viljelemällä perustettujen ja täysitiheänä säilytettyjen metsiköiden kasvua ja poistumaa.

Runkolukusarja menetelmää, jossa puuston kehitysennuste tehdään läpimittaluokittain, on käytetty varsinkin silloin, kun tarkoituksena on tutkia järeän puuston lisääntymistä ja arvonkasvua. Se on yleensä suuritöinen ja hakkuutoiminta voi muuttaa suuresti laskelman lähtöolettamuksia.

Kasvufunktioita, joissa kuutiokasvu on selitettävänä muuttujana, on käytetty ennenmuuta varsinaisissa kasvututkimuksissa mutta myös jonkinverran metsätalouden järjestelyssä.

Kasvuprosenttimenetelmää on käytetty paljon varsinkin Pohjoismaissa ja Suomessa. Tähän asti on kuutiokasvuprosentti esitetty yleensä taulukkona metsikön iän funktiona erikseen eri puulajivaltaisille ja erilaista tiheyttä oleville metsiköille. Suomessa yleisesti käytetty tuottohakkauslaskelma erilaisine kehitelmineen on kasvuprosenttimenetelmä. Sen viimeisimmissä muodoissa kuutiokasvuprosentti on sopivien puustotunnusten määrittämä regressioyhtälön selitettävä muuttuja.

Pohjapinta-ala-pituusmenetelmässä pyritään erikseen arvioimaan puuston pohjapinta-alan ja pituuden kehittyminen sekä näiden yhteistuloksena kuutiomäärän kasvu.

Jatkuva inventointi, jossa puusto arvioidaan määräajoin ja seurataan poistumaa mittaamalla kannot tai hakkuutilastolla, muodostaa järjestelmän, jonka tietojen varassa voidaan puuston kehittymistä projisioida myös tulevaisuuteen.

Tähän asti käytettyjen menetelmien tarkastelun pohjalla voidaan tehdä eräitä päätelmiä käsillä olevan työn suuntaviivoiksi. Kasvun ja poistuman ennustetta tarvitaan silloin, kun metsätalouden järjestelyssä pyritään käyttämään hyväksi maan ja puuston tuotannolliset mahdollisuudet. Puusto on tuottava, orgaaninen elementti, jota ilman ei ole kasvua eikä hakattavaa. Metsätalouden järjestelyssä pyritään säilyttämään tietty, ennalta määrättävissä oleva, tuotantoon sidottu puusto, jonka kasvu on tunnettava, jotta voitaisiin arvioida hakattavissa oleva puumäärä. Tai jos hakkuumäärä on riippuvainen talouden tarpeista, on kyettävä arvioimaan tuotantoa ylläpitävän puuston kehittyminen.

Metsäalueella puusto koostuu suuresta määrästä mitä erilaisimpia metsiköitä. Metsätalouden järjestelyssä ne kootaan tilastollisiksi ryhmiksi, joiden puitteissa myös kasvun ja poistuman ennuste tehdään. Näissä olosuhteissa ei ole ajateltavissa lyhyttäkään ajanjaksoa, jolloin samanaikaisesti kasvun kanssa ei olisi poistumaa hakkuun tai puiden kuolemisen vuoksi. Ennustemenetelmän tulee siten mukautua kasvu- ja poistumatapahtumaan, jossa kumpikin osatekijä vaikuttaa toinen toiseensa.

Johdonmukaisin laskelmissa käytettävä kuutiokasvun yksikkö käsittää koko runkopuun tilavuuden. Puuston järeyssuhteita samoin kuin poistuman puutavaralajikoostumusta voidaan seurata sopivien puustotunnusten avulla. Ennustepoistuman puutavaralajikoostumus on parhaimmillaankin suuntaa antava arvio.

Tutkimuksessa on pyritty selvittämään, mistä puuston tunnuksista prosenttina ilmaistu kuutiokasvun intensiteetti on riippuvainen. Sopivien puustotunnusten määrittämä kasvuprosenttifunktio on muodoltaan yksinkertaisempi kuin kuutiokasvun funktio (Kuva 1, s. 15). Periaatteessa on yhdentekevää käytetäänkö kasvua tai kasvuprosenttia selitettävänä muuttujana niin kauan, kuin kasvava kuutiomäärä on mukana yhtenä tunnuksena.

Poistuman puutavaralajisuhteiden, luonnonpoistuman ja ilmastonvaihtelun vaikutuksen arviointia käsitellään myös tutkimuksessa.

Kasvu- ja poistumatapahtuman teoria ja peruskäsitteet (ss. 17—22)

Kasvu- ja poistumatapahtuma (Lönnroth 1929), jonka osien ja niiden rakenteen kehittymisen ennuste käsittää n-vuoden pituisen jakson, on esitetty kaavamaisesti kuvassa 2 (s. 17). Tarpeelliset käsitteet ovat:

v = alkukuutio ennustejakson alussa
v_E = loppupuuston alkukuutio
v_D = poistuman alkukuutio
v_C = hakkuumäärän alkukuutio
v_M = luonnonpoistuman alkukuutio
V = loppukuutio jakson lopussa
D = poistuma jakson aikana
C = hakkuupoistuma jakson aikana
M = luonnonpoistuma jakson aikana
I = kokonaiskasvu jakson aikana

I_E = loppupuuston kasvu
I_D = poistuman kasvu
I_C = hakkuupoistuman kasvu
I_M = luonnonpoistuman kasvu
I_N = nettokasvu
n = ennustejakson vuosien lukumäärä
m = puolijakson vuosien lukumäärä

Kasvu- ja poistumatapahtuman eri osien keskinäinen riippuvuus on kuvattu kaavoilla (1)—(9).

Puuston kasvun intensiteetti-indeksinä (Kuusela ja Nyyssönen 1962) käytetään koronkorkolaskun jälkiarvotekijää $1.0p^m$, joka on määritetty kaavalla (10) ja joka voidaan laskea kaavalla (12) kasvu- ja poistumasarjoista tai inventointikoealojen mittaustuloksista. Kun alkukuutio v tunnetaan inventoinnin perusteella ja tuotannon ylläpitämiseksi tarpeellinen loppukuutio V on määritetty, niin ennustejakson puolivälissä saatavissa oleva poistuma (D) lasketaan kaavalla (11). Jos taas poistuma on ennalta määritetty, niin sen ja kasvun yhteistuloksena muodostuva loppukuution likiarvo saadaan kaavalla (16). Ellei jakson aikana ole poistumaa, on loppukuution kaava (13).

Muut tässä yhteydessä esitetyt kaavat sekä kuvat 3—5 valaisevat kasvun intensiteetti-indeksin matemaattista sisältöä. Lopuksi esitetään teoriaa valaisevia esimerkkejä (s. 21).

Kasvufunktiot (ss. 23—32)

Kasvun kuvaaminen regressioyhtälöllä ja yhtälön käyttäminen kasvun ja poistuman ennustetta laskettaessa tarjoaa monia etuja. Tällöin on kuitenkin syytä korostaa sitä, että selitettävän ja selittävien muuttujien välinen regressio on enemmän matemaattinen kuin kausaalinen ja että se ei välttämättä selitä kasvutapahtumaa (Petterson 1955, s. 27).

Kuutiokasvuprosentti selitettävänä muuttujana on tilastollisesti riippuvainen useista puustoluokkien tunnuksista, jotka ovat sekä selittävyydeltään että käytäntöön sovellettavuudeltaan eriarvoisia. Tältä osalta suuri osa tutkimuksen tuloksista on jo julkaistu (Kuusela ja Kilkki 1963).

Puuston koostuessa likimain tasaikäisistä metsiköistä kasvuprosentti, so. kasvun intensiteetti, on riippuvainen ennenmuuta puuston iästä. Ikä on myös suhteellisen helposti ja luotettavasti arvioittavissa oleva tunnus olosuhteissa, missä havupuut muodostavat pääosan puustosta.

Iän ohella kuutiomäärän merkitys kasvuprosentin vaihtelun selittäjänä on merkittävin. Se on myös koko suunnitelmallisen puuntuotannon tärkein suure ja arviointitoimitusten ensisijainen tavoite.

Kasvupaikan laadulla on suhteellisen vähäinen ja vaikeasti arvioitavissa oleva vaikutus kasvuprosenttiin. Syynä tähän on ilmeisestikin se, että iän ja kuutiomäärän yhdistelmä sisältää boniteetin vaikutuksen kasvuun. Kuitenkin Ruotsin metsien inventoinnin tuloksilla tehdyt laskelmat osoittavat (Taulukko 1, s. 28), että kasvuprosentti on sitä pienempi mitä epäedullisemmista kasvuolosuhteista on kysymys. Nykyisten tietojen valossa näyttää siltä, että hakkuutoiminnan alaisille metsille voidaan laskea kasvuprosenttifunktioita ilman maan laatua selittävänä muuttujana ja että funktiot tulisi laskea ilmastovyöhykkeittäin tai ottamalla jokin ilmaston hyvyyttä kuvaava indeksi, esim. termisen kasvukauden pituus, selittäväksi muuttujaksi. Jos maan laadun vaihtelualue on suuri, lisääntyy tarkkuus laskettaessa kasvuprosenttifunktiot erikseen boniteettiluokittain. Puuston pituus ja läpimitta parantavat kasvuprosentin regressioyhtälöiden selittävyyttä jonkin verran, mutta suuren metsä-alueen kasvuennusteen kannalta niillä ei näytä olevan käytännöllistä merkitystä.

Kasvuprosenttifunktiot on syytä laskea erikseen puulajivaltaisuuden perusteella ryhmitetyille metsiköille, jolloin samaan ryhmään sopivat parhaiten sellaiset lajit, joiden kasvun rytmi on samanlainen. Nuorena nopeasti kasvavat männiköt eivät sovi parhaalla mahdollisella tavalla yhteen kuusikoiden kanssa, jotka kasvavat alussa suhteellisesti heikommin, mutta säilyttävät paremmin kasvuintensiteettinsä vanhalla iällä (Kuva 7, s. 31).

Kun selitettävänä muuttujana on vuotuisen kasvun prosentti tai koronkorkolaskun jälkiarvotekijän prosenttiosa, niin käyttökelpoisimmaksi funktioksi osoittautui:

$$\log p_i \text{ tai } \log (1.0p_i^n - 1) = a + b \log t + c\,v$$

jossa t on ikä vuosissa ja v kuutiomäärä kuutiometreissä hehtaaria kohti.

Yrityksissä kehittää funktiota käyttämällä kuutiokasvua selitettävänä muuttujana ei päästy yhtä hyviin tuloksiin kuin kasvuprosentilla.

Kasvuprosenttifunktioita voidaan laskea joko kasvutaulukoiden tai kasvukoealojen perusteella. Kasvutaulukoista tulevat kysymykseen ennenmuuta sellaiset, joissa ovat edustettuna eri tiheyttä olevat metsikkösarjat (esim. Nyyssönen 1958; Nilsson 1961). Funktioiden merkitys alkuperäisiin taulukkoihin verrattuna on lähinnä siinä, että niitä voidaan käyttää taulukoiden vaihtelualueella riippumatta taulukoissa noudatetusta metsiköiden luokituksesta. Luonnollinen ja suora tie on laskea funktioita alkuperäisten koealojen perusteella.

Kasvutaulukoiden lukusarjoilla suoritetut laskelmat osoittavat, että kasvuprosentti on erittäin kiinteästi riippuvainen iästä ja kuutiomäärästä. Näiden kolmen tunnuksen yhteiskorrelaatio on 0.98—0.99 (ss. 26—27 ja kuva 6). Alkuperäisiä kasvukoealoja käytettäessä yhteiskorrelaatio ei ole yhtä suuri, mikä on luonnollista, koska kasvutaulukoiden arvot ovat tasotettuja. Etelä-Suomessa mitattujen koealojen tuloksilla yhteiskorrelaatio vaihteli välillä 0.93—0.90 ja Pohjois-Suomen männikkökoealoissa se oli 0.68. Viimeksi mainitun yhteiskorrelaatiokertoimen pienuus johtuu ennenmuuta siitä, että aineistosta puuttuivat nuoret metsiköt.

Pohjapinta-ala-pituusmenetelmä (ss. 33—39)

Pohjapinta-ala-pituusmenetelmää kokeiltiin mittaamalla 27 koealaa käsittävä männikkökoealojen aineisto (Taulukko 4). Mittauksessa ja laskennassa käytettiin relaskooppikoealaa ja keskipuumenetelmää. Varsinaisen laskennan lähtötunnuksia olivat pohjapinta-ala ja keskipituus mittaushetkellä ja 5 vuotta aikaisemmin. Laskentaa kuvaavat kaavat (1—7) ovat esitetyt sivuilla 35—36. Pohjapinta-alan ja keskipituuden kasvuprosentille, so. jälkiarvotekijän prosenttiosalle, laskettiin regressioyhtälö, jossa pohjapinta-alan kasvuun nähden selittävinä muuttujina ovat rinnankorkeusikä ja pohjapinta-ala sekä keskipituuden kasvuun nähden rinnankorkeusikä ja keskipituus (vastaavat yhtälöt I ja VI taulukossa 6, s. 37). Sahapuuosuuden prosentin kehittymistä tutkittiin keskimääräisen poikkileikkauspinta-alan funktiona (Kuva 8, s. 35).

Pohjapinta-ala-pituusmenetelmä näyttää sopivan parhaiten metsiköittäisiin laskelmiin. Se tarjoaa nopean menetelmän likimääräisten kasvutaulukoiden valmistamiseksi.

Puutavaralajien arvioiminen kasvun ja poistuman ennusteen yhteydessä (ss. 40—47)

Metsätalouden järjestelyssä edellytetään, että puustosta irroitettavissa oleva poistuma arvioidaan myös puutavaralajeittain. Koska poistuman rakenne riippuu paljon hakkuutavasta ja markkinasuhteista, on tulevaisuuden poistuman rakenteesta tehty arvio parhaimmillaankin summittainen ja suuntaa antava. Yleensä riittää, kun arviossa erotetaan sahatukit, ainespinotavara, polttopuu tai ns. ohutpuu ja hukkapuu.

Tuotostaulukoiden (esim. Nyyssönen 1958) perusteella voidaan todeta, että säännöllisesti hoidetuissa metsiköissä poistuman rakenne on kiinteästi riippuvainen puulajista, kasvupaikan laadusta, metsikön iästä tai kehitysluokasta ja hakkuutavasta. Tutkimuksessa käytetyn koeala-aineiston (Taulukko 7, s. 42) mukaan vastaavaa riippuvuussuhdetta ei ole nykymetsissä metsiköiden laadun ja rakenteen suuren vaihtelun vuoksi.

Likimain puhtaissa metsiköissä koko puuston ja myös hakattavaksi ehdotetun puuston osan puutavaralajisuhteet ovat riippuvaisia ennen muuta keskiläpimitasta ja keskipituudesta. Kuvassa 9 ja 10 (s. 44) on esitetty pystypuuston puutavaralajisuhteiden kehittyminen tuotostaulukoiden perusteella sekä taulukossa 9 ja 10 (ss. 46—47) tutkimuksen koealametsiköistä leimatun puuston sahatukkiosuus keskipituuden ja keskiläpimitan funktiona.

Tuotostaulukoiden perusteella voidaan todeta, että mikäli puustoa hakataan jonkin metsänhoidollisen järjestelmän mukaan, niin hakattavissa oleva sahatukkien osuus lähitulevaisuuden poistuman kuutiomäärästä on riippuvainen hakkuutavasta ja nykypuuston sahatukkien osuudesta (Taulukko 8).

Edellä esitetyn perusteella näyttää mahdolliselta arvioida hakkuusuunnitteen puutavaralajirakenne inventoinnissa mitatun puuston rakenteen, metsikköryhmän kehitysvaiheen ja hakkuutavan perusteella. Mikäli hakattava puusto arvioidaan inventoinnin yhteydessä, on puutavaralajisuhteet arvioitavissa keskiläpimitan ja keskipituuden sekä niiden kasvun perusteella.

Kasvun vaihtelu (ss. 48—54)

Koska kasvu pääasiassa ilmaston muutosten johdosta voi vuosittain vaihdella aina 30—40 % ja 5—10 vuoden keskiarvoinakin 10—20 % verrattuna pitkän ajan keskiarvoon, on vaihtelu tavalla tai toisella otettava huomioon kasvua arvioitaessa ja ennustettaessa. Tavallisimmin se tapahtuu laskemalla ns. vuotuisia kasvuindeksejä riittävän monen vuoden sädekasvun perusteella ja eliminoimalla iän kasvua pienentävä vaikutus.

HAGBERG (1959) on kuvannut kolme vaihtoehtoista menetelmää, joista yhdessä tutkitaan ns. indikaattorimetsiköiden kasvua, toisessa pyritään selvittämään kasvu maan ja ilmaston ominaisuuksien funktiona ja kolmannessa kootaan sädekasvujen näyte ilmastoalueittain. Viimeksi mainittua menetelmää on käytetty eniten Pohjoismaissa.

Tässä tutkimuksessa kokeiltiin indikaattorimetsiköillä ja koelaskelmat osoittivat, että kun tarkoituksena on saada ilmastoindeksi inventointia edeltäneille vuosille, niin ellei keskimääräistaso perustu vähintään 70 vuoden pituisen jakson sädekasvusarjalle, niin indeksin arvo vaihtelee sattumanvaraisesti ja suuresti riippuen siitä, minkälaiseen vaihtelun »aallokkoon» tasotus sattuu (Kuva 11 s. 51 ja taulukko 11 s. 52).

Koska hakkuilla käsitellyissä metsiköissä on tasotettava myös hakkuiden vaikutus, vaatii se suurta puiden lukumäärää. Laskelmien vähentämiseksi on menetelty mm. siten, että aikaisemman inventoinnin indeksisarjaan on liitetty 20—30 vuosiluston perusteella saatu uusi sarja. Edellä mainitusta vaihtelun aallokosta johtuen tällainen indeksisarjojen toisiinsa liittäminen on sattumanvaraista ja summittaiseen tulokseen johtavaa (kuva 12, s. 53). Edelleen ilmeni koelaskelmissa, että saman metsikön puissa on vaihtelu hyvinkin yksilöllistä ja että 5 vuoden keskiarvoja käytettäessä 20 puun perusteella saadun indeksin (kun keskiarvo on 100) keskivirhe on 3—5 yksikköä.

Päätelmänä voidaan todeta, että tähänastisessa käytännössä on kasvuindeksillä voitu todeta vaihtelun suuruusluokka, mutta ei ole voitu täsmälleen määrittää, kuinka paljon jonkin jakson kasvua pitäisi korjata sen muuttamiseksi keskimääräistasoon.

Luonnonpoistuma kasvu- ja poistumaennusteen yhteydessä (ss. 55—57)

Luonnonpoistuman merkitys kasvu- ja poistumaennusteen yhteydessä riippuu ennen muuta metsätalouden voimaperäisyydestä. Jos suuri osa metsiköistä on pitkiä aikoja hakkuutoiminnan ulkopuolella, niin luonnonpoistuma on suuri. Säännöllisin väliajoin harvennetuissa metsiköissä se on taas pieni. Luonnonpoistuma on suurilla alueilla yleensä otettu huomioon kasvututkimusten ja pysyvien koealojen perusteella saatuna summittaisena arviona. Esim. Suomessa sen on arvioitu olleen vuonna 1927 6 % koko poistumasta, vuosina 1948—54 5—4 % ja vuosina 1955—61 2 %. Vuonna 1927 luonnonpoistuman arvio oli 2.55 milj. m^3 vuotta kohti ja vuonna 1961 1 milj. m^3. Ruotsissa on arvioitu luonnonpoistuman olleen viime vuosina niin pieni, että sitä ei tarvitse ottaa erillisenä määränä huomioon tasevertailuissa.

Taulukoissa 12 ja 13 (s. 56) on esitetty luonnonpoistuman suuruus hakkaamattomissa männiköissä ja taulukossa 13 Meltauksessa suoritetun koearvioinnin tulos. Jos kiertoaika on 80—90 vuotta ja ikärakenne tasainen, niin vuotuinen luonnonpoistuma on harventamattomissa Etelä-Suomen männiköissä kasvutaulukoiden mukaan 1.1 %, kuusikoissa 0.9 % ja koivikoissa 1.4%puuston kuutiomäärästä. Meltauksen koearvioinnin mukaan se on sikäläisissä satunnaisesti hakatuissa 90—130 vuotiaissa männiköissä 0.21—0.30 % kuutiomäärästä. Vastaava prosentti Suomen metsätasearvoissa oli vuonna 1927 0.19 %, 1938 0.15 %, vuosina 1948—50 0.14 % ja vuosina 1955—61 0.08 %. Evon hoitoalueen koealamittauksissa metsään lahoava luonnonpoistuma todettiin merkityksettömän pieneksi.

Tavoitepuustoon tähtäävän hakkuulaskelman kaavio (ss. 58—65)

Ruotsin, Norjan ja Suomen hakkuulaskelmamenetelmiin suoritetun katsauksen (ss. 58—61) perusteella on todettavissa, että menetelmissä on viimeaikoina pyritty yhä selvemmin ottamaan lähtökohdaksi nykypuusto ja kehittämään sitä ns. tavoitepuustoa kohti. Tavoitepuusto ja varsinkin ennustejakson loppuun asetettu välitavoite vaikuttavat suoranaisesti hakkuusuunnitteen suuruuteen,sillä suunnite on nykypuuston, välitavoitteen ja kasvun funktio (KUUSELA ja NYYSSÖNEN 1963).

Taulukossa 14 (s. 63) on esitetty, miten kasvun ja poistuman ennuste tapahtuu laskennallisesti. Inventoinnin perusteella saadut nykypuuston tunnukset on esitetty sarekkeilla 1—6 ja sarekkeilla 7 ja 8 on esitetty 10 vuoden laskentajakson jälkeinen tavoitepuusto. Sarekkeessa 9 on esitetty esimerkissä käytetyt kasvuindeksit.

Taimistometsiköille ja varsinkin silloin, kun kaikki puut eivät inventoinnin hetkellä ulotu rinnantasalle, on ennuste tehtävissä parhaiten sopivaa kasvutaulukkoa käyttäen. Niille metsikköryhmille, joita ennustejakson aikana käsitellään harventavilla hakkuilla, lasketaan kasvun ja poistuman ennuste kaavalla (10) s. 19, kun taas niille metsiköille, joiden puusto poistetaan kokonaan jakson aikana ja jakson keskelle oletettuna, saadaan poistuma kertomalla alkupuusto kasvuindeksillä. Hakkuusuunnitteen sahapuu- ja hakkuutähdeosuus arvioidaan likimääräisesti taulukon 8 ja kuvan 9 perusteella (ss. 14 ja 45). Sahapuun määrä kuutiojaloissa saadaan sopivalla keskimääräiskertoimella.

Ehdotukset (ss. 65—66)

Tulosten perusteella voidaan esittää seuraavia ehdotuksia kasvun- ja poistumaennusteen arvioimiseksi suurelle metsäalueelle.

Laskennan yksikkönä on runkopuun kokonaiskuutio.

Inventoinnin tulosten perusteella kuvattavissa oleva nykypuusto ryhmitetään kehitys- tai ikäluokkiin. Kunkin luokan puustolle asetetaan ennustejakson loppuun välitavoite, joka on tarpeen tuotannon ylläpitämiseksi ja askel kohden lopullista tavoitepuustoa. Alkupuusto, välitavoite ja puuston kyky kasvaa määräävät jokaisesta luokasta irroitettavissa olevan hakkuusuunnitteen.

Puuston kykyä kasvaa voidaan kuvata kasvuprosentilla ja varsinkin korkolaskun jälkiarvotekijällä, joka sopii hyvin kasvu- ja poistumatapahtumaan. Tällaista kasvuindeksiä kuvataan regressioyhtälöllä, jossa indeksi on selitettävä muuttuja ja jossa tehokkaimmat selittävät muuttujat Suomen olosuhteissa ovat puuston ikä ja kuutiomäärä. Indeksi on syytä laskea erikseen eri puulajivaltaisuutta oleville metsiköille ja laskelmien tarkkuutta lisää, jos yhtälöt lasketaan erikseen myös laaja-alaisille boniteettiluokille ja ilmastovyöhykkeille. Toinen mahdollisuus on ottaa maan laatu ja ilmasto muuttujina yhtälöön, mutta tämä vaihtoehto vaatii lisätutkimuksia.

Erikoistuvissa kasvututkimuksissa on merkitystä monilla muillakin puustotunnuksilla kuten pohjapinta-alalla, pituudella, läpimitalla jne. Pohjapinta-ala-keskipituusmenetelmä näyttää tarjoavan edullisen mahdollisuuden valmistaa nopeasti likimääräisiä kasvutaulukoita.

Kasvuindeksiyhtälöitä voidaan laskea joko inventoinneissa mitattujen kasvukoealojen tai kasvutaulukoiden perusteella.

Hakkuusuunnitteen puutavaralajisuhteet on arvioitavissa likimääräisesti ja ko. tarkoitusta varten riittävän tarkasti nykypuuston puutavaralajisuhteiden perusteella, sillä puuston tuotannollisen tilan kehittäminen edellyttää, että eri kehitysvaiheiden metsiköistä poistetaan esim. sahapuuta vain tietyssä suhteessa metsikön sahapuumäärään. Lisäksi on otettava huomioon puuston puutavaralajisuhteiden kehittyminen iän funktiona. Arviointi on suoritettavissa nopeasti käyttämällä aputaulukoita ja kehityssarjoja. Puuston tai puuston osan puutavaralajisuhteet ovat taas varsin tarkasti keskiläpimitan ja keskipituuden funktioita.

Luonnonpoistuma näyttäisi olevan parhaiten tutkittavissa pysyvillä koealoilla. Siitä saadaan likimääräisiä tietoja myös inventointikoealoilla. Luonnonpoistuma on ennenmuuta metsikkötyypin, iän ja tiheyden funktio. Säännöllisesti hakatuissa metsissä sen merkitys on vähäinen ja se on arvioitavissa summittaisesti.

Ilmaston vaihteluiden vaikutus voidaan ottaa kahdella tavalla huomioon: Vuotuiskasvuindeksiä tutkimalla selvitetään ns. keskimääräisen kasvun taso, johon verrataan mitattua kasvua. Indeksisarjan perustana tulisi olla vähintään 70 vuoden pituisen jakson vuotuiskasvut. Toisessa vaihtoehdossa kasvukoealoja mitataan jatkuvasti, ja kun niiden perusteella lasketaan kasvufunktioita, niin funktiot antavat keskimääräisen kasvun siltä ajalta, jonka puitteissa koealatietoja on käytettävissä.

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