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CLIMATIC VARIATION IN RADIAL GROWTH OF SCOTS PINE AND NORWAY SPRUCE AND ITS IMPORTANCE IN GROWTH ESTIMATION

MÄNNYN JA KUUSEN SÄDEKASVUN ILMASTOLLINEN VAIHTELU JA SEN MERKITYS KASVUN ARVIOINNISSA

Songkram Thammincha

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SELOSTE:

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PREFACE

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Helsinki, 27 February 1981

SONGKRAM THAMMINCHA

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1. INTRODUCTION

11. Aspects of tree growth

Tree growth can be expressed in different terms. In forestry, growth can be defined according to two principles, biology or mensuration. Biologically speaking, tree growth refers to the formation of new tissues and, subsequently, to an increase in size (BAKER 1950, p. 281). From the point of view of mensuration, tree growth may be simply defined as a change in tree dimensions (ILVESSALO 1965, p. 106). These dimensions are traditionally referred to as diameter, height and stem form.

Height growth results from the activity of primary apical meristematic tissues, while the activity of secondary lateral meristematic tissues produces diameter growth (LEIKOLA 1969, HUSH *et al.* 1972 p. 292–307). Form growth can be determined through observation of the progression of tree height together with the development of diameter at different heights along the stem over different periods of time.

The determination of height and form growth development actually requires either successive observations over a certain period of time or the measurement of diameter growth by means of the annual rings at different heights along the stem; the former is very time-consuming, while the latter is possible only on trees which produce distinct annual rings.

In practical forestry, more attention is always paid to diameter growth since diameter growth represents about 2/3 to 3/4 of the total amount of volume growth, whereas height and form growth account for 1/4 to 1/3 (ILVESSALO 1956). Therefore, diameter growth is usually regarded as the most important variable in volume growth determination.

Diameter growth comprises the growth of stem radii that develop in a certain fashion under given circumstance. The annual radial growth of a tree growing under natural conditions tends to increase rapidly till it reaches a maximum; thereafter it begins to decline, first rather rapidly and then gradually at a slower rate as the tree ages (MIKOLA 1950). The age at which the tree reaches the culmination of growth depends on many factors, *i. e.* tree species, site quality, competition among trees etc. However, the trend in growth performance changes after stand treatment has taken place. Forest fires and other damaging agents are also important factors influencing the growth performance of trees.

Stand density is a decisive factor influencing the diameter growth of trees; as a stand becomes denser the competition among trees increases and the diameter increment, as a result, decreases (BRAATHE 1952, NELSON 1952). In contrast, the diameter increment increases significantly with wider spacing (RUDOLF 1951, RALSTON 1953, BYRNES and BRAMBLE 1955). The thinning intensity will thus directly affect the diameter growth of trees. It is generally supposed that the highest rate of diameter increment is associated with heaviest thinning (ALEXANDER 1960). At any degree of stand density, however, the development of radial growth in various directions along the stem of an individual tree is also influenced by the distance to neighbouring trees.

For tree species which form distinct annual rings, increment boring is a very useful method for determining diameter growth. However, it must be kept in mind that the accuracy of diameter growth determinations based on increment cores depends in the first place on the shape of the stem. A noncircular stem and elliptical ring pattern often produce errors in the calculations. It is known that under certain environmental conditions trees may grow faster in one compass direction than in other directions (AVERY 1975, p. 116).

A tree growing on a slope responds to this stress situation by developing an elliptically-shaped stem. The highest radial growth rate in the stem of a broadleaved tree growing on a slope occurs on the up-hill side, the reverse being the case in conifers (LAURENCE 1950; HAASE 1970; KOZLOWSKI 1971, p. 91; HOCKER 1979, p. 71).

In an open stand, the wind strongly affects the development of radial growth, especially in trees growing at the edge of the stand (SPURR and BARNES 1973, p. 124–128). As a result, trees affected by wind will have eccentric stem cross-sections, the largest diameter being found along the direction of the prevailing wind. The largest radius develops on the lee side in conifers and on the windward side in broadleaved trees (ASSMAN 1970, p. 57–63).

12. Growth assessment

Assessment of the growth of individual trees and forest stands is an important activity in practical forestry. As timber management is increasingly being regarded as a form of business, the accurate estimation of growth becomes very important since crucial decisions rest directly upon it (DAVIS 1966, p. 65). From the standpoint of practical forest management, the growth of stands is of greater interest. However, the growth of individual trees has first to be considered, since a forest stand is an aggregation of individual trees.

Growth in terms of volume production is the final aim of growth estimation in forest management. Nevertheless, the basic components of volume growth (*e.g.* diameter, height, and form growth of individual trees) are of particular importance as a gateway to obtaining the volume growth of trees and stands.

There are different methods of growth estimation, each having a different level of accuracy. The methods that give accurate results commonly require a large work input, the simple methods, on the other hand, often being inaccurate (STRAND 1958). The selection of growth estimation methods is generally based on the purpose of estimation, available budget, and accuracy required.

The methods of growth estimation can be divided into two groups, direct and indirect methods. Direct methods are based on analysis of a particular stand in terms of measured variables, growth being estimated directly from these measurements. Indirect methods include the use of growth and yield tables. As a matter of fact, application of yield tables is a typical indirect method. The estimation process is basically a comparative one since it is assumed that the growth of a particular stand will follow some definable and predictable pattern in relation to the trend established by the yield tables.

The yield table method essentially involves comparing a particular stand with the known performance of other stands as defined by yield table data (NYYSSÖNEN 1956). Yield tables for fully-stocked stands are compiled from the data for natural normal stands. The primary characteristics of a particular stand are age, site, and density, the yield table figures being adjusted using these characteristics to give the growth figure for the stand in question.

Yield tables for managed stands are more applicable than normal yield tables. The tables are prepared from the data of stands subjected to different degrees of management, cutting in particular. Different kinds of tables are available for different stand treatments. Variable density yield tables are becoming more and more preferable, since they include the data from different cutting alternatives, especially thinnings of various intensity. Such tables are commonly known in northern Europe as "yield tables for stands treated with repeated thinning". These tables are used more as a guide-line for silvicultural treatment than as a basis for growth estimation.

A list of growth and yield tables for use in Finland can be found in the publication by KOIVISTO (1959), which contains growth and yield tables for natural normal stands and growth and yield tables for thinned stands. The list includes the results of growth and yield studies carried out in Finland, *i.e.* by ILVESSALO (1920), NYYSSÖNEN (1954, 1957) VUOKILA (1956, 1957) etc.

Since diameter growth is an important variable in the assessment of the volume growth of trees and stands, the direct methods of growth estimation may be divided into two groups: the methods that include increment boring and those that do not.

Of the different methods available, Jonson's method (JONSON 1928) has been widely used to estimate the volume increment percentage of stands in Norway, Sweden, and Finland. According to this method, the stand volume increment percentage is the sum of the basal area increment percentage and the form height increment percentage. The method requires data about annual ring widths and height growth.

Radial growth derived from increment cores and the height growth during the preceding period, usually 5 years, can be used as a basis for the calculation of stand volume at the beginning of the period. Stand growth is subsequently determined as the difference between the present volume (or volume at the end of the period) and the volume at the beginning of the period. This type of growth calculation is employed in the National Forest Inventory in Finland and Sweden.

Stand table projection based on the growth during the preceding 5-year period has been modified and used in the forest mensuration training course of the University of Helsinki since 1964. The methods involve the determination of growth in terms of volume and monetary value for the next 5-year period on the basis of the growth performance during the preceding period.

Application of tree and stand functions has become a standard method of growth estimation. Such functions include a number of independent variables which can be used in different cases. Since the calculation of future growth is still more or less based on past growth, the radial increment during the preceding period has been one of the most important independent variables (NYYSSÖNEN and MIELIKÄINEN 1978). If accuracy is the criterion of growth estimation, the radial growth of the preceding period should therefore be included. However, the inclusion of increment boring is time-consuming and, consequently, increases the costs of data collection. Moreover, increment boring may damage the tree stem (VUOKILA 1976).

The accuracy of growth estimation methods based on increment boring depends, to some extent, on the amount of variation in the ring widths of the trees in the stand. It is known that the variation in ring width among trees from different stands is greater than that among trees within the same stand. LANGSÆTER (1934) demonstrated that the variation in ring widths of the trees growing in a forest area of 100 hectares could be as high as 40 to 50 % when expressed as the variation coefficient, the variation increasing slightly with an increase in the size of the forest area. TRAMPLER and SIKORA (1956) found that the variation in ring widths within a stand was of about the same magnitude as the relative variation in volume growth, which equalled approximately 44 % (variation coefficient). In addition, GIERUSZYNSKI (1956) also found that the variation in the ring width of trees was 60 % among 3 spruce stands, compared with 25 % within diameter classes.

In the case of volume growth estimation methods which incorporate increment boring, the greater the variation in the ring width the smaller is the difference in the accuracy yielded by different methods. Therefore the choice of method depends on other factors, *i.e.* how volume is to be be estimated (STRAND 1958).

13. The importance of climatic factors in growth studies

Of the climatic factors influencing the growth of forest trees, temperature and precipitation have the greatest effect on diameter growth. The effects of temperature and precipitation vary from locality to locality and also among tree species. This variation is well-illustrated by the differences in the widths of annual rings (LIBBY *et. al.* 1976, SCHWARZ 1979).

In North America, one of the pioneers in the study of the relationships between the widths of tree rings and climate is DOUGLASS (1919, 1928, 1936). He concluded that rainfall was the most important factor affecting the width of annual rings. Among his successors in North America, MILLER (1950, 1951), SCHULMAN (1956), and TRYON *et al.* (1957) reaffirmed the results of the influence of rainfall on the annual ring widths of various tree species.

In addition to in North America, the amount of rainfall was also found to have a strong influence on the annual ring widths of trees in central and southern Europe, as shown in the investigations by CALISTRI (1962), CHRISTIE and LINES (1975), MILLER and COOPER (1976), BRETT (1978), and others.

In the northern coniferous zone, where the amount of rainfall is normally adequate, the growth of trees has been shown to be highly dependent on summer temperatures, other climatic factors being of minor importance

(HUSTICH 1947, 1949, 1956; SIRÉN 1961; MIKOLA 1962; MATTHEWS 1976). The role of temperature as a growth-limiting factor is also reflected by the smaller number of tree species to be found in the cold climatic zone, as compared to the number in the warmer climatic zones where precipitation adopts an increasingly important role.

The range of temperature within which the growth of Scots pine and Norway spruce usually takes place has been studied by MORK (1941), LADEFOGED (1952), EKLUND (1954, 1957), JONSSON (1969), LEIKOLA (1969), KISHCHENKO (1978), and others. The radial growth patterns of pine and spruce indicate a differing dependence on climate, temperature in particular. The radial growth of spruce is strongly dependent on the temperature during the early summer, while that of pine depends on the temperature during mid- and late summer (ORDING 1940, MIKOLA 1950, ANDERSSON 1953, GLEBOV and LITVINENKO 1976). Although temperature usually has a stronger influence on the radial growth of trees in northern Europe, a firm relationship has occasionally been found between radial growth and precipitation, as in the investigations carried out by HOLMSGAARD (1956) in Denmark, SLÅSTAD (1957) in Norway, JONSSON (1969) in Sweden, and KÄRENLAMPI (1972) in Finnish Lapland.

It is known that trees grow at different rates on sites of different forest site type. However, NÄSLUND (1942) found that the radial growth patterns of spruce growing on different types of site, located near to each other, were surprisingly alike, and that the radial growth of spruce at different altitudes was very similar. EKLUND (1954, 1967) demonstrated the difference in the radial growth of trees of different age classes. FIEDLER (1978) concluded, in his investigation on the growth of a spruce stand in East Germany (DDR), that the influence of weather on the width of annual rings is more marked in young stands than in old ones. Moreover, the radial growth of pine and spruce in northern Europe varies with longitude, and, for instance, annual ring index series for the same latitude in Finland and Norway have almost no common features (MIKOLA 1956).

The factors which most commonly bring about growth variation are stand treatment, especially cutting, and forest fires and other damaging agents (*e. g.* storms, insects). On the other hand, climatic variation may also produce results which resemble the effects of those factors (MIKOLA 1950). Hence, erroneous deductions can be made in growth studies if the effect of climatic variation is not taken into consideration (ILVESSALO 1956b).

Attention has been paid in Finland to the effect of climatic variation on growth assessments in both the National Forest Inventory (*e. g.* ILVESSALO 1942, 1956b; TIIHONEN 1979) and in different growth studies. Moreover, it is of special importance to take the effect of climatic variation into account when comparing the results of forest inventories carried out in different years (MIKOLA 1950, 1956, 1978).

14. Growth indices

Tree ring analysis is a typical means of investigating the effect of climatic variations on tree growth during a period lasting for a number of years. The width of an annual ring must be converted into an annual ring index if the growth of different years or periods is to be compared. This procedure requires the computation of normal radial growth from trees growing under natural conditions, or trees subject to regular silvicultural treatment if natural stands are not available.

Many researchers have employed a great variety of methods for computing normal radial growth, ranging from occular adjustment to the use of mathematical functions: in North America (DOUGLASS 1919; FRITTS 1960, 1963; FRITTS *et al.* 1969), and in northern Europe (ERLANDSSON 1936, ORDING 1940, NÄSLUND 1942, MIKOLA 1950, JONSSON 1969, HARI and SIRÉN 1972).

The annual ring index (or ring width index, or growth index in some other cases) is the ratio between the actual ring width of a given year and the expected ring width for the corresponding year. In northern Europe, the annual ring index is usually expressed as a percentage, the normal ring width being defined by the index 100. Annual ring indices are always computed sequentially so as to represent a series for a given group of material, especially for a certain area or locality. The ring widths of different groups must be converted into annual ring indices before averaging, otherwise the variance of the series will be dominated by fast-growing trees (FRITTS 1976, p. 266–267).

Annual ring index series are very often constructed to represent the growth rhythm in regions or parts of the country, *i.e.* southern or northern Finland. However, it must be borne in mind that the difference in growth performance of trees from different localities or areas, may be very large during some years or longer periods. It is thus necessary to construct annual ring index series for a single locality, since the growth estimation in practical forest management is usually carried out on the basis of individual forest areas.

MIKOLA (1950) pointed out that Finland is climatically a uniform area, climatic variations being slight or medium, subsequently producing tree rings which are of the complacent or medium type. Close correlation exists between annual ring index series from different parts of the country. However, this does not imply that the magnitude of growth, or of the indices, is similar in different parts of Finland. Trees in different areas respond differently to the same degree of change in growth factors even though they may exhibit a similar rhythm of growth. This is an important precondition in estimating the growth of trees or stands because several growth estimation methods are based on average characteristics.

As the width of an annual ring may differ very much from those produced in the preceding or succeeding years, so do the annual ring indices. In order to reduce the annual variation, the periodic growth, *i.e.* the combined width of rings produced over a period of 5 or 10 years, is more appropriate for use in growth estimation. Periodic growth is also more preferable as regards the accuracy of the measurements. Field measurement of annual rings is associated to some extent with systematic error: the smallest ring widths are found to be too large and the largest ring widths too small (SEIP 1957). Generally speaking, the relative accuracy of the measurement increases when longer periods are used. However, errors may occur in annual ring counting over longer periods, *i.e.* the number of annual rings may be erroneously counted as 9 or 11 in a 10-year period, such errors rarely occurring in the case of 5-year periods (STRAND 1958).

15. The aim of the study

The aim of the present study is to investigate the importance of the climatic variation in tree growth for increment estimation, so as to be able to evaluate the relative accuracy of growth estimation based on increment boring in comparison to the other methods. In order to achieve this aim, the investigation will deal with the features of climatic variation as indicated by the radial growth of Scots pine and Norway spruce in different localities and in southern Finland as a whole. The effect of the number of sample trees on the reliability of annual ring indices will also be discussed.

2. MATERIAL AND METHODS

21. Field work

The main task of the present study is to construct annual ring index series representing the growth rhythm of trees in different localities and in southern Finland as a whole. In order to achieve this, increment cores from pine and spruce stands are required. It would be desirable that the increment cores be collected from trees in untreated stands in order to exclude the effects of other factors, since the variation in tree growth due to climatic conditions can only be analyzed satisfactorily on the basis of annual ring material obtained from such stands (EKLUND 1954). However, it is difficult to find stands or even parts of stands which have remained untreated. This is especially the situation in southern Finland where a major part of the forest land is privately-owned and subjected to various silvicultural measures. Likewise, the experimental forests administered by the Finnish Forest Research Institute have generally been treated with different measures. Nevertheless, the study was carried out in these experimental forests owing to the good facilities and the availability of necessary information.

Facilities such as some instruments, workers, transportation to the worksites, accommodation etc. were provided by the research stations. Some important information about the forest stands was obtained from management plans. Discussions with forest officers and forest workers also provided more details about the forest stands prior to starting the field work. In addition, the experimental forests have been treated more regularly than the other forests. They were therefore preferable in the investigation on growth variation, since there were not enough natural forests available.

Forest maps with stand stratification and stand descriptions were available for preliminary screening of possible sample stands. The material was gathered from stands representing the most common forest site types: *Oxalis-Myrtillus* Type (OMT), *Myrtillus* Type (MT), *Vaccinium* Type (VT) and *Calluna* Type (CT) (cf. CAJANDER 1949). The stands were all more than 40 years old. The first 20 years (or annual rings) were excluded so as to avoid the fluctuations typical of the early development of the radial growth of trees (cf. MIKOLA 1950, p. 40–42). Selection of the sample stands was made on the basis of the stand descriptions prior to locating the sample plots in the field. An attempt was made to achieve even distribution of the sample plots over the area under study in each locality.

The direction and the distance from a certain point, usually at the boundary of each selected stand, to the center of the sample plot (or plots) were planned in advance in order to avoid personal bias in locating the sample plots. The direction and the distance were changed only in cases where the plot was found to be situated on a steep slope, or in extremely abnormal stands (*e.g.* with very low density, or severe damages).

The following characteristics were recorded for each sample plot: 1) forest site type, 2) slope, 3) aspect, 4) dominant species, 5) basal area in square meters per hectare as determined using a relascope, and 6) evidence of stand damage and recent stand treatment.

The relascope plot techique was employed in selecting sample trees. The selection of sample trees in proportion to their basal area means that trees are sampled approximately in proportion to their growth potential (STAGE 1960). A relascope with a basal area factor of 1 (BAF 1) was used in most cases. In this case, each tree counted with the relascope represented a basal area of 1 m²/ha. Every tree counted with the relascope was given a preliminary number. The number was pinned on the tree stem at breast height, facing the center of the plot. This number also indicated the point for diameter measurement and increment boring. The number of sample trees from which the increment cores were to be taken varied from 10 to 25, depending upon the stand density and distribution of stem sizes. In the case of dense stands with trees of approximately the same size, sample trees were selected systematically from the numbered trees, usually by choosing every second tree. In other cases, all numbered trees were counted as sample trees.

The diameter of each numbered tree was measured, from two sides of the stem (one from the side facing the center of the plot and the other at right angles to it), both at an accuracy of 1 mm. The height of the median tree (by basal area) in each sample plot was measured with a Blume-Leiss hypsometer.

Increment cores which were taken with an increment borer at the side of the sample trees, extended from the stem surface to the pith. It was not easy to obtain increment cores which extended right into the pith or very close to it. Inexperienced workers took more time, particularly during the first few days of the working period. At least twice the number of borings, compared with the total amount of sample cores, had to be made before all the material had been collected. Increment cores were marked and stored between pieces of corrugated cardboard for future treatment.

Most of the material was collected during May to August in 1978 and the rest in 1979, mainly from the experimental forests of the Finnish Forest Research Institute. All localities were in southern Finland (see Fig. 1). General information about the sample stands is presented in the appendices.

The material comprised 2160 sample trees (increment cores), 1004 of which were Scots pine and 1156 Norway spruce. Only 146 sample cores, 61 pine and 85 spruce, were gathered in 1979. Some cores were discarded, since they were in a condition that made accurate measurement impossible. Consequently, the total number of samples amounted to 2118, 998 pine and 1120 spruce.

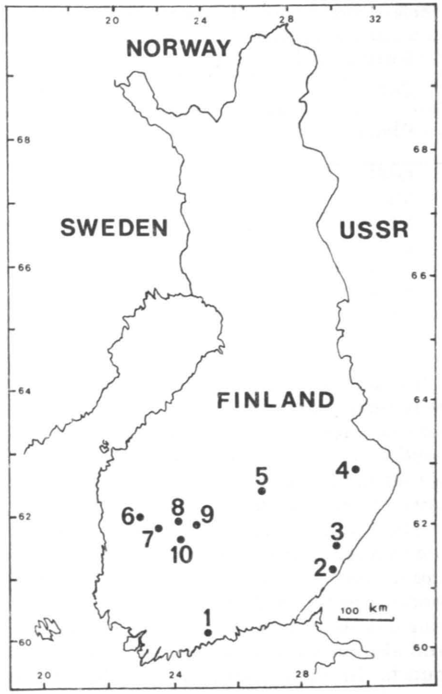

Fig. 1. Location of the study forests. 1) Ruotsinkylä, 2) Laikko, 3) Punkaharju, 4) Koli, 5) Kaupinharju, 6) Alkkia, 7) Saarijärvi, 8) Vessari, 9) Kaltila, 10) Hyytiälä.

22. Measurement of increment cores

The increment cores were measured at the Department of Forest Mensuration and Management of the University of Helsinki, using a Swedish annual ring measuring machine which determines the width of each annual ring to an accuracy of 0.01 mm.

The cores were completely dry when the measurements were started in September 1978. Some of them were broken, usually into two or three pieces, and a number of them, as mentioned earlier, were so badly broken that they could not be reassembled. Those broken in the field were marked so that they could be correctly assembled later. Unmarked pieces of broken cores were carefully connected and rechecked using a microscope, so as to ensure that they had been assembled correctly. The core was then fixed in the machine and cut with a surgical blade so as to make the wood cells clearly visible.

Prior to measurement, the cores, prepared as mentioned above, were soaked for a short time in dilute (0.5–1.0 %) aniline sulphate solution. The cores thus expanded to their original length, the solution simultaneously accentuating the demarcation of the annual rings (MIKOLA 1950). The dilute aniline sulphate solution turned the spring wood light yellow, distinguishing it from the more yellowish summer wood.

Table 1. Distribution of sample plots by age class and forest site type.

Forest site type	Age class, years						Total
	<61	61–80	81–100	101–120	121–140	>140	
	Number of sample plots						
OMT	3	11	–	6	1	1	22
MT	5	6	9	13	12	3	48
VT	2	7	2	5	6	4	26
CT	–	4	3	2	1	1	11
Total	10	28	14	26	20	9	107

Sample pre-treatment and measurement were made successively on the trees from the same sample plot so that the cores and ring widths could be compared and checked within the group of trees growing under the same environmental conditions.

The width of the annual rings was measured using a microscope of 7.5-times magnification, starting from the outermost ring and working forwards the pith. The width of each ring was automatically printed on a paper roll and also on a paper tape by means of a tape punch. In many cases, the widths of the annual rings were of a size which required higher magnification (50X) in order to distinguish between the cells of spring wood of a given year and the summer wood of the preceding year.

A special check was later made in order to ensure that every annual ring was attributed to the correct year. The best core in each group (an unbroken core with clear annual rings) was first selected and measured as the standard core, measurement of the other cores being subsequently compared with it.

23. Calculation procedures

231. Determination of normal radial growth

At first, the calculations were carried out to assess the normal radial growth, standardize the ring widths and thus determine the annual ring index series. These calculations were made separately for pine and spruce.

It is essential for the study of growth variation that the magnitude of normal growth be first determined for the particular stand in question. However, it is rather difficult to determine the normal growth for the entire life cycle of trees, because the growth performance during the early life of a tree or a stand is not yet stabilized. In contrast, annual ring series for trees which have passed the culmination period of growth exhibit a decline in the growth rate with increasing age. The declining stage of growth approximately follows the form of a hyperbolic function. In the present study, an ideal curve representing normal radial growth was estimated by fitting a hyperbolic function to the data:

(1) $$Y_t = aX_t^{\,b}.$$

When converted to logarithms, this equation becomes

(2) $$\ln Y_t = \ln a + b \ln X_t,$$

where Y_t equals the width of the annual ring of an individual tree in year t and X_t the age of the stand in the corresponding year. Equal age was used for each tree of the sample plot in order to match the ring widths with the corresponding calendar year.

Correction due to logarithmic transformation was made by adding half of the squared residual standard deviation to the constant term in the determination of the expected ring width (MEYER 1941, quoted by NYYSSÖNEN and MIELIKÄINEN 1978, p. 11).

232. Determination of the indices for stand and local series

Annual ring indices were determined for each sample plot based on the arithmetic mean ring width of sample trees and the expected ring width of the corresponding calendar year. The index was expressed as a percentage. Hence

(3) $$I_t = 100 \cdot \frac{Y_t}{\hat{Y}_t},$$

where I_t = the ring width index for year t,
Y_t = the average ring width (of sample trees) in year t, and
$\hat{Y}_t$ = the expected ring width in year t.

The indices for particular sample plots were called *stand indices* and the sequence of stand indices called *stand series.*

The *local indices* were defined as the average stand indices (of the same locality) weighted by the number of sample trees. Accordingly,

(4) $$A_t = \frac{\sum_{i=1}^{k} I_{ti} \cdot n_i}{\sum_{i=1}^{k} n_i},$$

where A_t = the local index in year t,
I_{ti} = the stand index of plot i in year t,
n_i = the number of sample trees in plot i,
i = 1,2, . . . , k.

For the series from southern Finland, the index for a given year was the arithmetic mean of the local indices.

(5) $$M_t = \frac{\sum_{j=1}^{m} A_{tj}}{m},$$

where M_t = the mean index for southern Finland in year t,
A_{tj} = the index of local series j in year t,
m = the number of local series,
j = 1,2, . . . , m.

Since the estimation of annual growth is often associated with large errors, the emphasis in growth estimation is commonly placed on periodic growth during a 5-year period in particular. For this reason, 5-year moving average indices were computed for stand and local series as follows.

(6) $$\bar{I}_t = \frac{(I_t + I_{t-1} + I_{t-2} + I_{t-3} + I_{t-4})}{5}$$

(7) $$\bar{A}_t = \frac{(A_t + A_{t-1} + A_{t-2} + A_{t-3} + A_{t-4})}{5}$$

$\bar{I}_t$ denotes the 5-year average index for the current year t, which is the arithmetic mean of the annual ring indices for the year t and the other 4 preceding years. $\bar{A}_t$ and A_ts are correspondingly referred to as the indices for the local series. If, on the other hand, $\bar{I}_t$ is the average annual growth for a given period (5 years with t as the last year of the period), $\bar{I}_{t-5}$ is therefore the average annual growth of the preceding period.

233. Variation in growth indices

The variation in growth indices was studied in three categories.

1) Variation in growth indices of a given year between different stand series within the same locality.

2) Variation in growth indices between different local series.

3) Variation and correlation between growth indices of a particular local series and those of other local series.

Analyses of variance were employed in order to determine the extent of the differences between growth indices among the series.

Comparison of the indices between two series was also carried out. The variation between the indices of different series during a particular period was determined from the standard deviation of the differences.

(8) $$s_{12} = \sqrt{\frac{\sum_{t=1}^{N} (I_{1t} - I_{2t})^2}{N}},$$

where I_{1t} = the growth index of stand series 1 in year t,

I_{2t} = the growth index of stand series 2 in year t,

N = the number of years in the period for which the comparison is made,

t = 1,2, . . . , N,

$$\sum_{t=1}^{N} (I_{1t}-I_{2t}) = 0.$$

As the final analysis dealt with the comparison of growth estimation methods, the method involving increment boring and the method without it, the emphasis was laid on periodic growth during 5 years. The ring widths for the last 5 years are commonly used as a basis in growth estimation. The examination concentrated on two features of growth typically involved in growth estimation, actual growth and average growth.

The error in the estimation of future growth based on growth during the preceding period was determined by the formula:

$$(9) \quad s_{ag} = \sqrt{\frac{\sum_{t=1}^{N} (\bar{A}_t-\bar{A}_{t-5})^2}{N}},$$

where s_{ag} = the standard deviation of the differences between the indices of future and preceding periods,

$\bar{A}_t$ = the 5-year average index for a given period,

$\bar{A}_{t-5}$ = the 5-year average index for the preceding period,

N = the number of comparison pairs, and

$$\sum_{t=1}^{N} (\bar{A}_t-\bar{A}_{t-5}) = 0.$$

234. Index series based on subsamples

A pooled series for southern Finland was calculated on the basis of stand series using the following formula:

$$(10) \quad P_t = \frac{\sum_{i=1}^{k} I_{ti} \cdot n_i}{\sum_{i=1}^{k} n_i},$$

where P_t equals the index of pooled series in year t.

For testing purposes, the material was divided into subsamples as follows.

1) Plots No. 1, 3, 5, . . . , 13 from every locality,
2) Plots No. 1, 5, 9, and 13 from every locality,
3) Plots with < 10 sample trees,
4) Plots with < 15 sample trees,
5) Plots with < 20 sample trees,
6) Plots with ≥ 20 sample trees, and
7) All sample plots.

The indices computed from local indices were also included in this analysis as the 8th alternative.

3. ANNUAL RING INDICES

31. Index series from different localities

The annual ring indices of Scots pine for the years 1910 to 1977 are presented in Table 2, and for Norway spruce in Table 3. A visual comparison of annual ring index series for pine from different localities is shown in Fig. 2, and for spruce in Fig. 3. The average annual ring index in different periods is also presented in Table 4.

It can be seen from Fig. 2, that the growth performance of pine in eastern and western localities was different, especially from 1960 onwards. The growth rate of pine in eastern localities increased sharply in 1967, while the variation in growth in western localities seemed to be more moderate.

East-west differentiation was found in the growth of spruce in certain periods during the 1950's and 1970's. Since spruce demonstrated low growth potential in every locality during the 1950's, the growth rate of spruce in western Finland was distinctly lower than that in the east. On the other hand, spruce in western Finland displayed a higher growth potential during the 1970's.

The results of analysis of variance on the stand indices in each locality are shown in Table 5. The differences between pine stand series were nonsignificant in Punkaharju, Koli II, Kaltila, Vessari, and Hyytiälä. Likewise, the differences between spruce stand series were nonsignificant in many localities, except in Ruotsinkylä, Punkaharju, and Koli II.

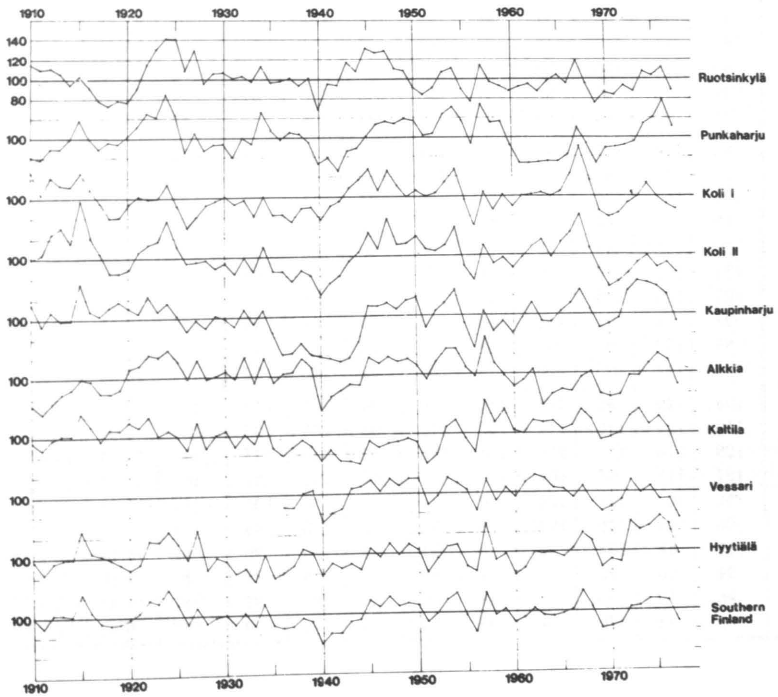

Fig. 2. Annual ring indices for Scots pine.

Table 2. Annual ring indices for Scots pine in different localities.

Year	Locality									Average indices for southern Finland	Standard deviation [1]		
	Ruotsinkylä	Punkaharju	Koli I	Koli II	Kaupinharju	Alkkia	Kaltila	Vessari	Hyytiälä		s_1	s_2	s_3
	Annual ring index												
1977	89	111	86	82	92	88	77	73	96	88	11.16	16.75	12.64
1976	112	139	91	92	120	113	105	93	127	110	16.74	19.94	15.19
1975	104	120	99	87	128	119	116	92	135	111	16.45	20.24	14.81
1974	108	114	112	99	132	109	108	105	125	112	10.19	16.67	9.06
1973	88	96	99	92	133	97	124	99	121	105	16.10	17.11	15.27
1972	94	92	92	82	123	97	117	112	130	104	16.55	17.17	15.86
1971	84	90	81	73	96	78	100	92	89	87	8.73	16.32	10.04
1970	87	89	77	68	90	76	96	85	92	84	8.99	18.79	10.64
1969	76	73	84	85	86	79	93	80	84	82	5.95	19.77	7.24
1968	96	94	115	107	105	101	114	90	111	104	9.00	9.80	8.68
1967	119	110	149	141	125	96	124	106	119	121	16.54	27.74	13.67
1966	96	82	121	123	111	82	108	95	102	102	15.01	15.20	14.69
1965	104	75	103	113	103	84	104	103	95	98	11.76	11.91	11.97
1964	98	75	99	98	92	79	113	104	99	95	11.83	12.87	12.42
1963	88	74	102	116	93	68	110	114	99	96	16.98	17.50	17.69
1962	95	73	100	109	112	104	113	117	100	103	13.20	13.48	12.87
1961	92	73	99	98	97	93	100	110	84	94	10.54	12.31	11.21
1960	88	92	88	87	81	87	103	96	77	89	7.68	14.16	8.65
1959	93	116	100	98	93	98	125	105	99	103	10.79	11.25	10.48
1958	97	115	85	91	83	110	111	92	92	97	11.80	12.13	12.12
1957	114	134	103	111	104	138	134	114	129	120	13.67	25.34	11.38
1956	77	93	69	75	67	97	82	82	81	80	9.94	23.11	12.37
1955	90	117	95	88	92	106	96	103	86	97	9.99	10.48	10.30
1954	111	131	126	129	126	126	114	110	109	120	9.00	23.26	7.48
1953	107	123	113	111	113	126	107	116	107	114	6.95	16.07	6.11
1952	91	104	102	105	105	113	79	98	95	99	9.89	9.94	9.98
1951	84	102	99	107	88	95	70	89	81	91	11.50	15.25	12.70
1950	91	117	105	120	119	108	92	115	104	108	10.98	13.81	10.18
1949	108	119	99	113	116	116	96	115	110	110	7.97	13.45	7.23
1948	110	114	110	112	107	113	93	108	99	107	6.96	10.44	6.49
1947	129	116	125	138	113	118	91	115	111	117	13.14	22.60	11.20
1946	127	113	105	107	110	111	87	102	97	107	11.11	13.11	10.43
1945	132	101	127	124	110	118	94	114	106	114	12.54	19.44	11.00
1944	108	89	116	104	74	90	70	108	84	94	16.17	17.51	17.26
1943	117	86	108	95	58	91	73	106	90	92	18.17	20.26	19.85
1942	94	66	96	80	54	85	73	85	86	80	13.50	25.25	16.90
1941	96	79	90	73	58	79	85	81	91	81	11.30	22.80	13.90
1940	69	73	76	62	59	65	74	71	79	70	6.65	32.74	9.53

Table 2. Continued.

Year	Locality									Average indices for southern Finland	Standard deviation [1]		
	Ruotsinkylä	Punkaharju	Koli I	Koli II	Kaupinharju	Alkkia	Kaltila	Vessari	Hyytiälä		s_1	s_2	s_3
	Annual ring index												
1939	101	95	89	81	62	107	89	104	101	92	14.05	16.35	15.25
1938	94	104	88	86	74	116	95	101	106	96	12.46	13.16	12.98
1937	101	105	74	75	63	103	88	87	89	87	14.45	19.81	16.56
1936	98	98	81	85	62	102	80	88	82	86	12.26	19.07	14.21
1935	97	107	81	85	84	94	87		77	89	9.75	15.28	10.96
1934	113	126	100	110	107	118	115		100	111	8.89	14.85	8.00
1933	98	94	80	85	93	94	92		74	89	8.26	14.59	9.31
1932	103	100	97	100	108	119	101		87	102	9.14	9.36	8.97
1931	101	80	92	83	91	98	89		82	90	7.58	13.54	8.42
1930	107	94	100	94	99	105	105		95	100	5.30	5.30	5.31
1929	106	93	96	89	102	101	101		99	98	5.45	5.72	5.54
1928	96	87	92	97	90	98	88		87	92	4.58	9.82	4.99
1927	130	105	80	95	98	117	114		127	108	17.00	19.15	15.71
1926	109	85	69	94	87	99	87		97	91	11.86	15.36	13.05
1925	142	123	92	111	102	116	100		113	112	15.50	20.38	13.79
1924	142	145	113	137	116	128	106		126	127	14.18	31.80	11.20
1923	131	121	99	118	107	121	101		116	114	11.02	18.80	9.64
1922	115	125	98	114	123	123	120		117	117	8.61	19.99	7.37
1921	91	111	101	106	105	112	110		94	104	7.85	8.82	7.57
1920	77	102	93	89	111	109	115		88	98	13.32	13.49	13.59
1919	79	94	80	85	118	89	107		93	93	13.45	15.33	14.45
1918	73	96	79	85	112	85	108		98	92	13.82	16.25	15.02
1917	79	89	96	105	103	85	97		102	94	9.32	11.02	9.86
1916	93	100	108	121	108	98	111		105	105	8.67	10.47	8.22
1915	103	118	125	158	136	100	124		127	124	18.37	31.45	14.83
1914	95	99	112	116	99	89	102		98	101	8.81	8.91	8.70
1913	107	89	113	131	98	85	102		97	103	14.55	14.84	14.16
1912	111	89	121	125	107	76	98		94	103	16.55	16.79	16.13
1911	110	78	104	104	93	65	88		82	90	15.29	18.35	16.89
1910	115	81	125	100	115	73	95		95	100	17.79	17.79	17.81
SD	15.8	18.0	16.6	18.9	19.7	16.4	14.5	12.5	14.9	11.9	Average s_1=11.67		

[1] s_1=absolute standard deviation,
s_2=standard deviation of the indices from normal growth (index of 100), and
s_3=relative standard deviation (variation coefficient).

Table 3. Annual ring indices for Norway spruce in different localities.

Year	Locality: Ruotsinkylä	Laikko	Koli I	Koli II	Kaupinharju	Saarijärvi	Kaltila	Vessari	Hyytiälä	Punkaharju	Average indices for southarn Finland	Standard deviation [1] s_1	s_2	s_3
	Annual ring index													
1977	77	99	108	103	108	103	93	98	103	105	100	9.20	9.21	9.23
1976	120	107	110	104	113	125	119	120	133	103	115	9.70	18.91	8.40
1975	104	92	107	99	109	107	99	101	121	85	102	9.83	10.15	9.60
1974	93	91	104	94	101	93	97	105	109	104	99	6.28	6.35	6.34
1973	71	93	91	84	88	69	73	71	87	83	81	9.13	22.01	11.27
1972	93	108	101	95	102	111	106	113	122	94	104	9.35	10.48	8.95
1971	105	95	86	79	95	106	113	110	114	105	101	11.70	11.73	11.61
1970	103	119	104	91	102	101	109	106	104	99	104	7.16	8.21	6.90
1969	94	107	107	109	98	97	108	111	98	118	105	7.60	9.07	7.26
1968	92	106	98	96	94	90	100	107	98	90	97	6.01	6.74	6.19
1967	87	109	119	117	101	82	103	99	93	105	101	11.96	12.06	11.78
1966	92	103	118	114	103	93	113	111	93	98	104	9.72	10.51	9.36
1965	107	96	108	112	103	92	116	122	94	111	106	9.84	11.75	9.27
1964	99	90	104	108	99	93	116	115	95	90	101	9.60	9.64	9.51
1963	102	99	123	121	105	104	137	125	108	103	113	12.78	18.51	11.4
1962	114	93	102	104	103	86	119	114	94	113	104	10.83	11.70	10.39
1961	100	83	110	105	94	78	96	99	77	93	93	11.09	13.03	11.86
1960	100	101	120	115	108	91	103	97	83	105	102	10.80	11.07	10.56
1959	111	95	110	106	102	88	101	89	86	80	97	10.78	11.29	11.13
1958	82	75	80	74	80	86	85	75	78	69	78	5.27	23.37	6.73
1957	107	88	96	89	98	100	100	94	93	82	95	7.17	9.09	7.57
1956	78	70	87	78	84	82	80	77	75	75	79	4.90	23.08	6.24
1955	96	90	87	84	85	90	83	87	81	80	86	4.81	15.22	5.57
1954	99	102	115	114	104	92	87	75	87	107	98	12.85	12.99	13.08
1953	113	102	107	110	97	101	85	97	88	118	102	10.55	10.72	10.36
1952	112	97	104	97	86	90	74	84	81	102	93	11.73	14.03	12.65
1951	96	85	98	90	73	83	63	71	68	101	83	13.50	22.60	16.30
1950	93	90	85	85	82	95	77	86	82	114	89	10.33	15.61	11.62
1949	96	93	88	86	96	101	86	96	90	115	95	8.68	10.32	9.17
1948	105	106	100	100	107	107	91	97	96	118	103	7.57	8.09	7.37
1947	121	127	119	116	135	118	103	118	117	117	119	8.16	21.72	6.85
1946	130	111	113	107	119	103	94	101	105	119	110	10.50	15.03	9.53
1945	118	112	104	105	116	107	90	98	109	101	106	8.43	10.54	7.96
1944	110	102	100	93	101	97	81	93	99	107	98	8.12	8.32	8.27
1943	113	106	92	89	103	92	77	79	93	122	97	14.34	14.78	14.84
1942	92	82	84	75	87	93	74	76	92	72	83	8.12	19.96	9.82
1941	80	76	85	75	92	102	83	75	106	65	84	12.81	21.26	15.27
1940	104	101	86	84	120	133	93	83	127	77	101	19.85	19.87	19.70

Table 3. Continued.

Year	Locality: Ruotsinkylä	Laikko	Koli I	Koli II	Kaupinharju	Saarijärvi	Kaltila	Vessari	Hyytiälä	Punkaharju	Average indices for southarn Finland	Standard deviation [1] s_1	s_2	s_3
	Annual ring index													
1939	119	97	79	83	100	124	110	113	128	85	104	17.67	18.12	17.02
1938	133	123	77	87	98	117	119	138	139	117	115	21.17	26.30	18.44
1937	136	120	85	98	97	117	114	137	127	107	114	17.20	22.52	15.11
1936	135	107	92	111	101	114	114	129	113	101	112	12.88	17.84	11.53
1935	114	92	81	95	100	93	101		100	126	100	13.09	13.10	13.06
1934	108	109	91	115	116	121	130		126	146	118	15.51	24.60	13.14
1933	81	90	85	101	101	105	101		104	91	95	8.83	10.07	9.25
1932	74	116	93	111	105	110	123		113	120	107	15.23	17.05	14.20
1931	70	103	86	100	94	89	98		91	107	93	11.01	13.21	11.82
1930	72	98	89	118	94	107	120		98	126	102	17.12	17.31	16.71
1929	80	100	90	112	105	118	133		102	141	109	19.49	21.70	17.88
1928	66	72	70	95	76	91	99		85	108	85	14.56	21.83	17.20
1927	96	102	92	112		112	123		108	158	113	20.71	24.87	18.35
1926	85	99	91	113		110	115		108	144	108	18.02	20.00	16.67
1925	95	119	116	131		128	136		127	190	130	27.23	42.28	20.91
1924	108	127	132	141		121	131		120	182	133	22.18	41.45	16.71
1923	117	106	110	110		102	107		101	136	111	11.24	16.37	10.12
1922	128	117	111	116		117	119		117	118	118	4.73	19.69	4.02
1921	113	135	103	109		105	103		98	86	106	14.04	15.67	13.18
1920	110	108	94	98		89	96		89	68	94	13.08	14.57	13.92
1919	109	108	104	103		92	92		109	70	98	13.41	13.52	13.63
1918	85	83	71	80		78	77		86	61	78	8.28	25.31	10.67
1917	95	100		104		85	83		90	77	91	9.68	14.05	10.68
1916	101	102		103		84	87		91	86	93	8.30	10.92	8.89
1915	83	114		118		86	91		93	102	98	13.63	13.78	13.89
1914	88	106		109		82	83		82	78	90	12.53	16.74	13.96
1913	106	105		114		84	95		85	87	97	11.90	12.46	12.32
1912	102	97		106		80	93		81	68	90	13.67	17.72	15.26
1911	98	83		98		75	93		84	57	84	14.63	22.64	17.42
1910	76	63		80		77	92		85	40	73	17.16	33.57	23.42
SD	16.3	13.8	13.6	13.9	11.4	14.3	16.8	17.8	15.8	26.9	12.0	Average s_1=11.90		

[1] s_1=absolute standard deviation,
s_2=standard deviation of the indices from normal growth (index of 100), and
s_3=relative standard deviation (variation coefficient).

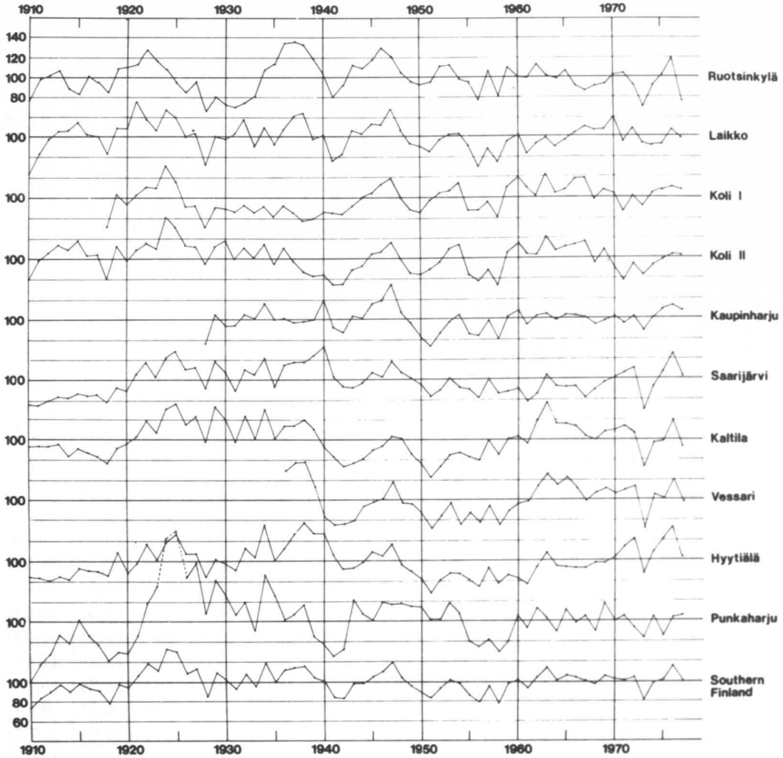

Fig. 3. Annual ring indices for Norway spruce.

Ruotsinkylä was the only locality where the differences between stand series were found to be significant, in both pine and spruce. Nonsignificant differences were also found between the local series.

The differences in stand indices between different calendar years were highly significant in most cases. Such differences were also found among the local series.

Tables 6 and 7 illustrate the results for the comparison between local indices for a period of 40 years (1938 to 1977), using standard deviation of the differences and the correlation coefficient as indicators.

Table 4. Average annual ring index for Scots pine and Norway spruce during different 10-year periods.

Species and locality	Period						
	1910–19	1920–29	1930–39	1940–49	1950–59	1960–69	1970–77
	Average annual ring index						
Scots pine							
Ruotsinkylä	97	114	101	109	96	95	96
Punkaharju	93	110	100	96	115	82	106
Koli I	106	93	88	105	100	106	92
Koli II	113	105	88	101	104	108	84
Kaupinharju	109	104	84	86	99	101	114
Alkkia	85	112	106	99	112	87	97
Kaltila	103	104	94	84	101	108	105
Vessari				101	102	102	94
Hyytiälä	99	106	89	95	98	97	114
Southern Finland	101	106	94	97	103	98	100
Norway spruce							
Ruotsinkylä	94	100	104	107	99	99	96
Punkaharju	73	133	113	101	93	103	97
Laikko	96	109	106	102	89	99	101
Koli I		101	86	97	97	111	101
Koli II	102	114	102	94	93	110	94
Kaupinharju			101	108	89	101	102
Saarijärvi	82	109	110	105	91	91	102
Kaltila	89	116	113	87	84	111	101
Vessari				92	84	110	103
Hyytiälä	89	106	114	103	82	93	112
Southern Finland	89	111	106	100	90	103	101

Table 5. Analyses of variance for annual ring index series from different sample plots in each locality, and for the indices from different localities.[1])

Locality		Scots pine			Norway spruce		
		MS	DF	F	MS	DF	F
Ruotsinkylä	Plots	1059.75	6	3.8399**	422.47	10	2.0387*
	Years	844.88	29	3.0613**	1367.64	29	6.5998**
Punkaharju	Plots	157.85	12	0.7464	1364.48	3	5.3322**
	Years	3378.32	89	15.9750**	1305.78	49	5.1027**
Laikko	Plots				9.64	7	0.0412
	Years				1692.67	69	7.2316**
Koli I	Plots	622.80	10	2.0435*	152.21	3	0.4948
	Years	2824.11	49	9.2664**	458.86	39	1.4918
Koli II	Plots	388.53	4	1.7631	553.74	9	4.3400**
	Years	1511.95	49	6.8610**	1691.71	29	13.2588**
Kaupinharju	Plots	1276.11	8	3.9552**	128.65	6	0.8751
	Years	2629.44	29	8.1497**	489.76	19	3.3318**
Alkkia	Plots	637.66	5	2.7043*			
	Years	1793.70	29	7.6071**			
Saarijärvi	Plots				127.77	3	1.0480
	Years				883.63	69	7.2476**
Kaltila	Plots	28.57	4	0.1106	3.82	3	0.0100
	Years	1151.20	69	4.4583**	1111.22	69	2.9173**
Vessari	Plots	1.86	3	0.0069	1.91	3	0.0138
	Years	671.34	41	2.4986**	1281.74	41	9.2667**
Hyytiälä	Plots	191.85	6	0.8339	195.88	7	0.7227
	Years	1844.01	49	8.0150**	2144.91	59	7.9136**
	Localities	67.30	8	0.4357	115.38	9	0.9382
	Years	1392.73	41	9.0166**	1033.53	41	8.4041**

[1]) Significance levels of the F-test: * P<0.05, ** P<0.01.

Table 6. Standard deviation of the differences (upper figure) and correlation coefficient (lower figure) between the local indices of Scots pine for 40-year period.

Locality	Ruotsinkylä	Punkaharju	Laikko	Koli I	Koli II	Kaupinharju	Alkkia	Saarijärvi	Kaltila	Vessari	Hyytiälä
Punkaharju	17.49 0.47										
Laikko	33.30 0.17	26.65 0.58									
Koli I	11.37 0.72	20.89 0.28	31.96 0.29								
Koli II	14.38 0.64	21.39 0.35	33.51 0.24	8.86 0.88							
Kaupinharju	20.96 0.39	20.06 0.53	22.89 0.72	19.46 0.51	18.90 0.58						
Alkkia	13.92 0.62	11.90 0.79	31.36 0.34	18.27 0.38	18.75 0.45	20.34 0.48					
Saarijärvi	22.64 0.36	18.51 0.64	26.67 0.60	26.30 0.13	27.53 0.16	21.86 0.55	21.26 0.49				
Kaltila	19.79 0.16	21.10 0.29	31.55 0.32	19.40 0.27	20.76 0.30	17.43 0.62	20.23 0.27	24.39 0.30			
Vessari	12.12 0.59	19.45 0.29	32.96 0.17	13.04 0.59	13.55 0.69	19.36 0.48	14.91 0.53	25.30 0.10	16.12 0.40		
Hyytiälä	14.90 0.48	16.40 0.56	26.72 0.59	16.80 0.40	19.58 0.34	15.16 0.73	15.22 0.56	15.99 0.73	13.25 0.65	15.15 0.40	
Southern Finland	11.54 0.65	12.20 0.77	24.72 0.73	12.52 0.64	13.95 0.66	12.27 0.87	11.70 0.73	17.01 0.70	14.02 0.57	11.66 0.59	8.38 0.84

Table 7. Standard deviation of the differences (upper figure) and correlation coefficient (lower figure) between the local indices of Norway spruce for 40-year period.

Locality	Ruotsinkylä	Punkaharju	Laikko	Koli I	Koli II	Kaupinharju	Saarijärvi	Kaltila	Vessari	Hyytiälä
Punkaharju	15.25									
	0.48									
Laikko	12.45	12.22								
	0.58	0.63								
Koli I	17.30	15.67	13.70							
	0.14	0.39	0.39							
Koli II	16.82	14.21	12.73	5.85						
	0.28	0.52	0.50	0.93						
Kaupinharju	12.83	15.74	9.71	11.80	12.06					
	0.51	0.35	0.68	0.52	0.56					
Saarijärvi	13.52	18.94	12.93	19.09	18.69	11.19				
	0.53	0.13	0.47	0.11	0.02	0.60				
Kaltila	17.88	19.97	15.83	16.58	14.86	15.02	16.39			
	0.34	0.20	0.39	0.37	0.49	0.47	0.38			
Vessari	15.56	16.88	13.79	17.28	15.42	14.94	15.57	7.89		
	0.50	0.44	0.56	0.31	0.47	0.48	0.46	0.89		
Hyytiälä	16.22	21.50	14.34	21.40	21.06	13.27	8.80	15.53	14.35	
	0.46	0.10	0.54	0.07	0.01	0.61	0.85	0.55	0.62	
Southern Finland	10.40	12.30	7.11	11.22	10.17	6.99	10.32	11.01	9.67	12.15
	0.69	0.61	0.81	0.52	0.65	0.81	0.63	0.75	0.84	0.68

32. Effect of the number of sample trees

A visual comparison of the indices for the pooled series for pine in southern Finland, as computed using different alternatives, is presented in Fig. 4 and for spruce in Fig. 5. The results suggested that a relatively small number of sample plots and trees is sufficient for determining the indices for southern Finland.

The results of analyses of variance (Table 8) indicate that the differences between stand series from different localities were generally significant. The differences between the indices for different calendar years were, as expected, highly significant in most cases.

For a further study of the effect of sample size, pine stands from Punkaharju and Koli and spruce stands from Hyytiälä were used as an example. The samples used for computing the local series were as follows:

Pine, Punkaharju		Pine, Koli		Spruce, Hyytiälä	
No. of plots	No. of trees	No. of plots	No. of trees	No. of plots	No. of trees
2	20	2	27	2	36
3	25	4	39	2	50
4	35	5	51	3	62
5	46	6	65	4	87
4	48	6	85	4	91
7	82	7	82	4	99
13	157	10	123	8	178
		11	140		

The annual ring indices for the local series of Scots pine in Punkaharju and in Koli and Norway spruce in Hyytiälä, as computed from different numbers of sample plots and trees, are presented in Figs. 6, 7, and 8 respectively.

The visual comparison indicated that a relatively small number of sample trees is sufficient for determining the indices for the corresponding localities.

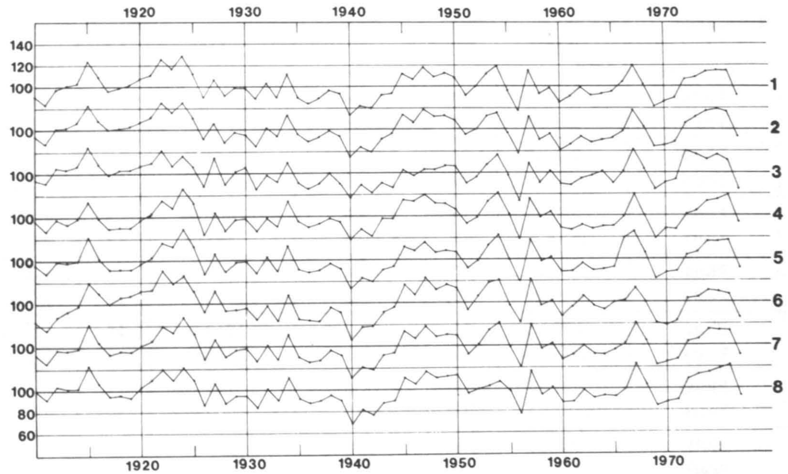

Fig. 4. Annual ring indices for the pooled series of Scots pine in southern Finland computed using different alternatives. Alternative 1) 39 plots and 525 trees; 2) 23 plots and 273 trees; 3) 17 plots and 80 trees; 4) 40 plots and 348 trees; 5) 55 plots and 605 trees; 6) 14 plots and 332 trees; 7) 69 plots and 937 trees; 8) local average.

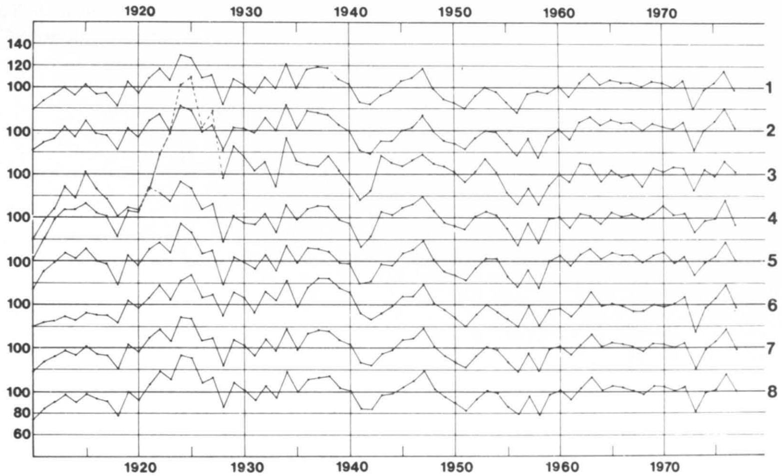

Fig. 5. Annual ring indices for the pooled series of Norway spruce in southern Finland computed using different alternatives. Alternative 1) 33 plots and 549 trees; 2) 17 plots and 288 trees; 3) 10 plots and 54 trees; 4) 23 plots and 218 trees; 5) 44 plots and 566 trees; 6) 20 plots and 469 trees; 7) 64 plots and 1035 trees; 8) local average.

Table 8. Analyses of variance on annual ring indices for different sample plots from which the pooled series for southern Finland were computed.[1])

Alternative		Scots pine			Norway spruce		
		MS	DF	F	MS	DF	F
1	Plots	784.88	38	2.2656**	1245.51	32	6.2680**
	Years	5856.38	29	16.9046**	2744.32	19	13.8107**
2	Plots	956.53	22	2.6421**	414.96	16	1.6278
	Years	4131.19	29	11.4100**	1920.01	29	7.5320**
3	Plots	713.53	16	1.3358	830.66	9	3.5977**
	Years	2550.70	29	4.7751**	881.56	19	3.8182**
4	Plots	934.74	39	2.4164**	680.18	22	3.0101**
	Years	6009.91	29	15.5363**	1580.56	19	6.9945**
5	Plots	992.35	54	2.6522**	1219.04	43	5.4566**
	Years	8055.55	29	21.5298**	3150.90	19	14.1039**
6	Plots	422.41	13	1.5132	291.15	19	1.1809
	Years	2101.34	29	7.5273**	2350.23	39	9.5322**
7	Plots	869.22	68	2.4392**	1099.47	63	5.1892**
	Years	9758.34	29	27.3837**	4579.42	19	21.6136**
8	Localities	89.45	10	0.4004	115.38	9	0.9382
	Years	1965.61	41	8.7977**	1033.53	41	8.4041**

1) Significance levels of the F-test: * P<0.05, ** P<0.01.

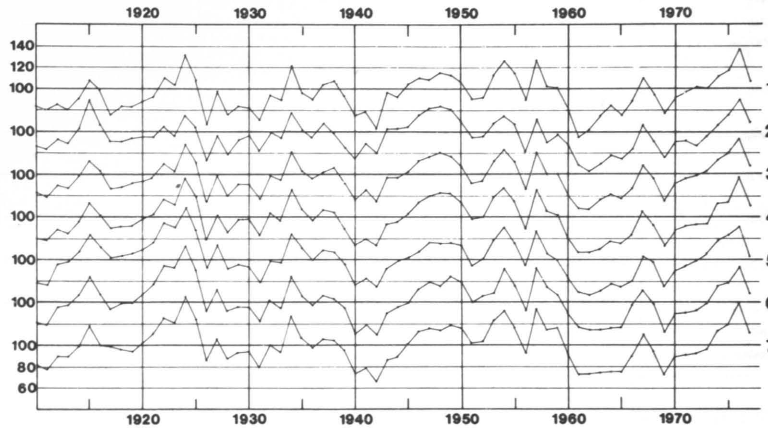

Fig. 6. Annual ring indices for the local series of Scots pine in Punkaharju computed from different numbers of sample trees: 1) 20 trees, 2) 25 trees, 3) 35 trees, 4) 46 trees, 5) 48 trees, 6) 82 trees, and 7) 157 trees.

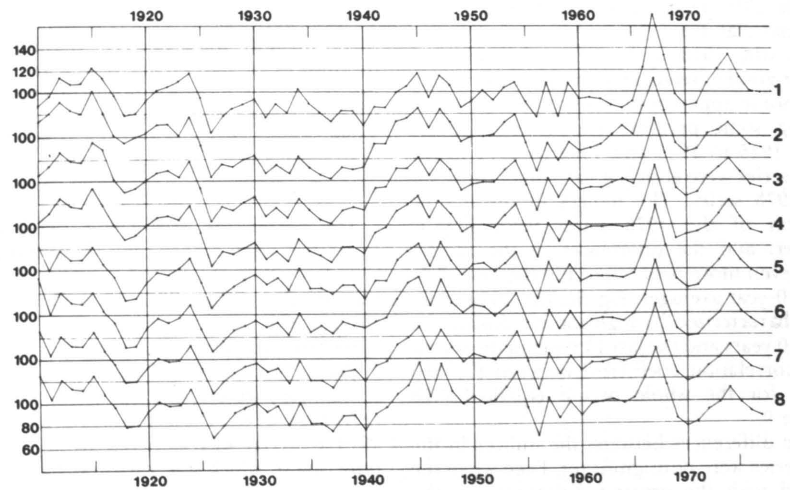

Fig. 7. Annual ring indices for the local series of Scots pine in Koli computed from different numbers of sample trees: 1) 27 trees, 2) 39 trees, 3) 51 trees, 4) 65 trees, 5) 85 trees, 6) 82 trees, 7) 123 trees, and 8) 140 trees.

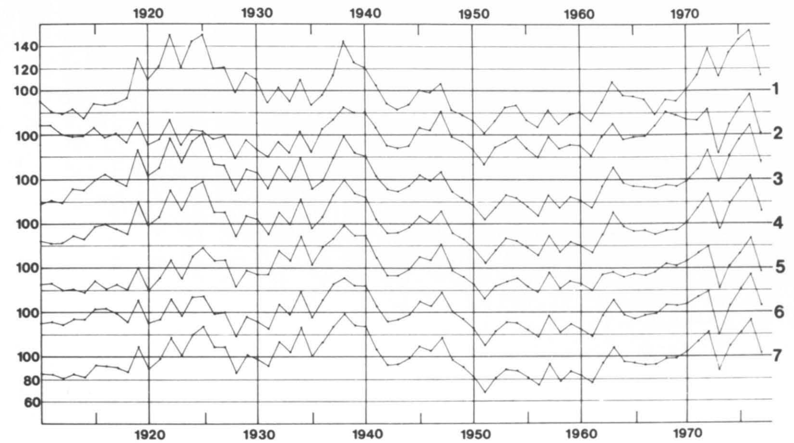

Fig. 8. Annual ring indices for the local series of Norway spruce in Hyytiälä computed from different numbers of sample trees: 1) 36 trees, 2) 50 trees, 3) 62 trees, 4) 87 trees, 5) 91 trees, 6) 99 trees, and 7) 178 trees.

33. Comparison with other series

331. Series from Hyytiälä

Additional annual ring indices were computed from 61 Scots pine sample trees gathered in 1979, using the same procedure as for the material from 1978. Although the two series (the 1978 and 1979 series) were in rather good agreement with each other, there were some apparent differences in the indices during some periods. The indices for the years 1915 to 1925 and 1962 to 1971 in the 1979 series were clearly greater than those for the 1978 series. The indices in the middle portion of the 1978 series were slightly greater, and the differences in the indices were even more pronounced in the case of 5- and 10-year averages (Fig. 9). The 1979 series was characterized by high indices during the first 10 years and the last 15 years in the series. The correlation coefficient between the two series for the whole period equalled 0.78 (Table 9).

The differences between the indices in the two series were nonsignificant. Even when the period with the greatest differences in the indices (from 1958 to 1977) was analyzed, the conclusion remained the same: nonsignificant differences between the two series and highly significant differences between the years.

Rather similar growth rhythms were found in the two spruce series. The similarity between the indices extended from 1915 to the end of the 1940's; thereafter the differences between the indices in the two series increased until the end of the period (1977), the indices of the 1979 series being slightly greater. The indices for the 1978 series were slightly larger from the beginning of the 1920's up until the end of the 1940's. These characteristics were clearly evident in the series for 5- and 10-year average indices.

The correlation coefficients between the two series were higher than 0.80, except for the last 10-year period, 1968–1977. As regards the comparison between pine and spruce, the spruce series were in better agreement with each other than those of pine: a smaller variation, and consequently higher correlation, were found.

As regards the characteristics of stands, the 1979 material was gathered from 7 stands, only one of which was a natural stand. Some stands were thinned during 1959 and 1960, and some were also fertilized during 1966 and 1968 (cf. Appendix IX). As a result, the average growth rate was clearly higher than

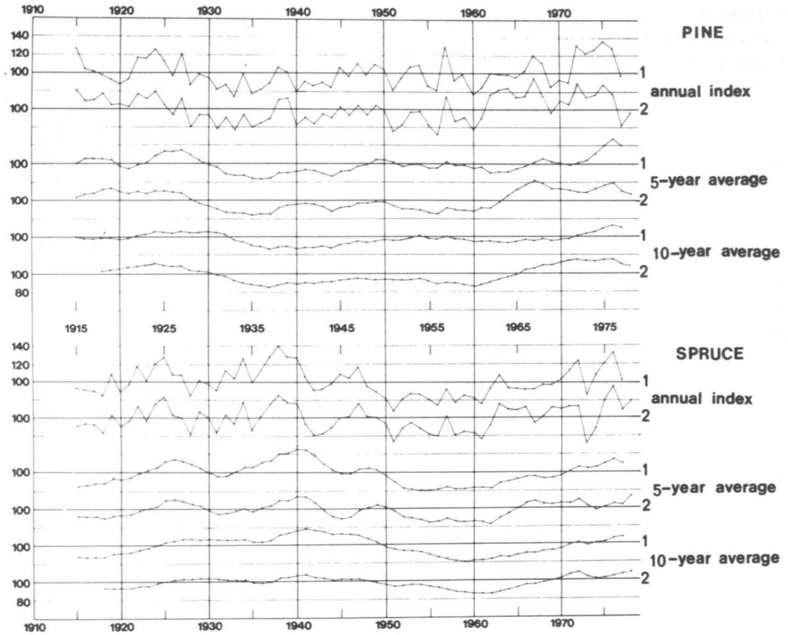

Fig. 9. Index series for two material groups from Hyytiälä in 1978 (series 1) and 1979 (series 2).

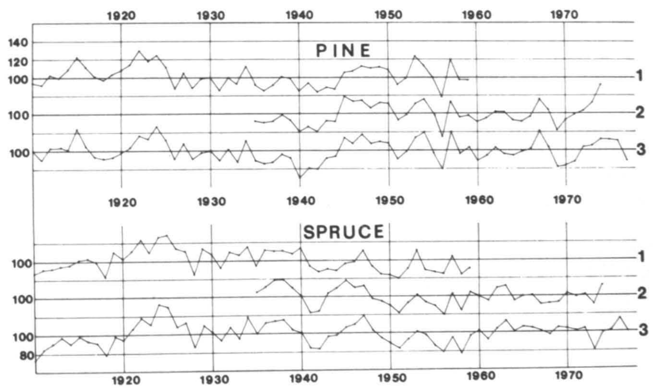

Fig. 10. Annual ring indices for southern Finland based on results from the 3rd National Forest Inventory and supplementary data (MIKOLA 1978), 1), the 6th National Forest Inventory (TIIHONEN 1979), 2) and the present study, 3).

Table 9. Standard deviation of the differences (cf. Equation 8), correlation coefficients, and the results from analysis of variance between the indices of the series based on the material collected from Hyytiälä in 1978 and 1979.[1])

Year	Scots pine		Norway spruce	
	s_{12}	Correlation coefficient	s_{12}	Correlation coefficient
1968–1977	11.05	0.80	9.99	0.79
1958–1977	12.99	0.72	9.73	0.81
1948–1977	12.03	0.74	8.99	0.85
1938–1977	10.79	0.76	9.25	0.83
1928–1977	9.85	0.80	9.15	0.83
1918–1977	10.08	0.78	8.53	0.85

Analysis of variance

69-year series		MS	DF	F
Pine	Series	6.0938	1	0.1302
	Years	390.3750	68	8.3387**
Spruce	Series	1.4219	1	0.0374
	Years	394.4249	68	10.3652**
20-year series		**MS**	**DF**	**F**
Pine	Series	198.0234	1	2.5277
	Years	480.8672	19	6.1381**
Spruce	Series	50.6250	1	1.0737
	Years	446.6776	19	9.4733**

[1]) Significance levels of the F-test: * $P<0.05$, ** $P<0.01$.

normal during the 1960's, particularly the growth of pine.

The majority of the stands in the 1978 material were fertilized during the end of the 1960's and the beginning of the 1970's, only a few being thinned in the beginning of the 1960's (one stand in 1959). The average annual growth had been on the increase since the beginning of the 1970's.

Some effects of these treatments can be seen in Fig. 9, especially during the last 15 years.

332. Series from the National Forest Inventories

An annual ring index series for southern Finland, obtained from the present study, was compared with the series based on the results of the following two National Forest Inventories:

1) The series from the 3rd National Forest Inventory (1951–1953) and supplementary data for the years 1910 to 1959, as presented by MIKOLA (1978).

2) The series based on the results from the 6th National Forest Inventory, for the years 1935 to 1974 (TIIHONEN 1979).

The series from the three different cases are presented in Table 10, and a visual comparison in Fig. 10. The results of the comparison between indices for pairs of series, as expressed by the standard deviation of the differences, were as follows:

Comparison pair	Standard deviation of the differences, index units	
	Pine	Spruce
3rd Inventory vs. 6th Inventory	5.12	9.27
3rd Inventory vs. present study	5.73	6.84
6th Inventory vs. present study	5.64	5.61

Table 10. Annual ring indices for the series for southern Finland based on (1) the 3rd National Forest Inventory and supplementary data (MIKOLA 1978), (2) the 6th National Forest Inventory (TIIHONEN 1979), and (3) the present study.

Year	Pine			Spruce			Year	Pine			Spruce		
	(1)	(2)	(3)	(1)	(2)	(3)		(1)	(2)	(3)	(1)	(2)	(3)
1974		132	112		112	99	1944	87	93	94	89	109	98
1973		112	105		80	81	1943	89	93	92	91	103	97
1972		103	104		102	104	1942	84	81	80	88	84	83
1971		99	87		99	101	1941	94	86	81	94	83	84
1970		93	84		103	104	1940	85	81	70	114	101	101
1969		82	82		93	105	1939	99	93	92	108	110	104
1968		104	104		92	97	1938	101	99	96	111	119	115
1967		116	121		91	101	1937	91	92	87	111	118	114
1966		97	102		101	104	1936	85	90	86	112	112	112
1965		91	98		100	106	1935	92	92	89	95	105	100
1964		93	95		95	101	1934	112		111	115		118
1963		101	96		111	113	1933	93		89	106		95
1962		102	103		109	104	1932	100		102	110		107
1961		95	94		95	93	1931	86		90	92		93
1960		91	89		100	102	1930	100		100	106		102
1959	97	98	103	91	104	97	1929	99		98	114		109
1958	97	96	97	84	85	78	1928	88		92	85		85
1957	120	113	120	104	103	95	1927	105		108	111		113
1956	78	75	80	85	80	79	1926	88		91	114		108
1955	100	98	97	87	90	86	1925	111		112	128		130
1954	113	116	120	89	94	98	1924	124		127	126		133
1953	123	111	114	111	102	102	1923	118		114	110		111
1952	99	99	99	91	94	93	1922	130		117	123		118
1951	92	93	91	80	82	83	1921	115		104	112		106
1950	108	111	108	84	90	89	1920	108		98	103		94
1949	111	112	110	85	95	95	1919	103		93	110		98
1948	110	106	107	94	98	103	1918	97		92	83		78
1947	114	115	117	111	112	119	1917	101		94	100		91
1946	107	114	107	99	110	110	1916	112		105	103		93
1945	106	119	114	97	119	106	1915	122		124	102		98
							1914	109		101	96		90
							1913	100		103	95		97
							1912	103		103	92		90
							1911	92		90	91		84
							1910	94		100	86		73

The results from the comparison revealed that the growth indices from the present study were in very good agreement with the growth indices based on the results from the National Forest Inventories, especially with those of the 6th Inventory. The differences between the indices for pairs of pine series were of about the same magnitude, ca. 5 %, while those for spruce varied from 5 % to 9 %, the greatest difference being between the series from the 3rd and 6th Inventory.

The results of the analysis of variance revealed that the differences between the indices of the three series for the years 1935 to 1959 were nonsignificant (F = 0.8342), while highly significant differences were found between the indices for different calendar years (F = 34.8881). In the case of spruce, the differences in the indices between the series were significant (F = 3.8697), while those for different calendar years were highly significant. The significant differences between the indices for the spruce series were due to the differences between the indices of the two National Forest Inventories. The correlation coefficient between pairs of indices for the pine series was approximately equal to 0.90, compared with ca. 0.65 in the case of spruce.

34. Variation of indices

341. Stand series

The standard deviation of the indices for the pine stand series in each locality are shown in Table 11, and for the spruce stand series in Table 12. Most localities included stand series covering a different number of years. The stand series covered an equal number of years in Vessari (42 years), as well as in Laikko, Kaltila, and Saarijärvi (70 years).

The number of years included in the series did not affect the magnitude of variation within the series. However, the variation within stand series from Ruotsinkylä seemed to have some relation to the number of years included: a shorter series resulting in a smaller variation.

The number of sample trees and the tree species composition seemed to have some effects on the variation within stand series. The standard deviation of the indices within pine stand series was comparatively large when only a few trees were sampled from stands in which pine was the minor species. On the other hand, the variation was generally smaller in stands where pine was the dominant species. In pure stands, however, the standard deviation varied irregularly from stand to stand, and the effect of the number of sample trees could not be clearly distinguished.

The figures were considerably different in the case of spruce. In Ruotsinkylä, the standard deviation of the indices within the spruce stand series in which spruce was the dominant species was smaller, as compared to that of pure stands. Similar results were also obtained from Laikko, Koli, Saarijärvi, and Vessari. However, the variation found in the spruce series from mixed stands in Hyytiälä was slightly larger than that for pure stands.

342. Local series

The variation in the annual ring indices, 5-year moving average indices, and 10-year moving average indices for pine in each locality, as expressed by standard deviation in index units, are presented in Table 13, and for spruce in Table 14.

For a single calendar year, the standard deviation of the indices among pine stand series within the same locality was as large as 47 index units (defined as Max.), as compared with 42 index units for spruce. The variation within the pine series was also in some cases as large as 49 index units (or 49 % due to the fact that the mean index of the series is 100), in comparison to 33 index units for spruce.

The standard deviation of the indices within local series ranged from 12 to 20 index units for pine, or 11 to 27 index units for spruce. The variation in the indices within local series was in most cases smaller than that of stand series on an average for the corresponding locality (cf. Tables 11 and 12).

A low standard deviation value for the indices in local pine series was accompanied by a greater difference between this standard deviation and the average standard deviation for the variation among stand series. For instance, this difference equalled 6.67 units (33.65 %) in Hyytiälä, 6.42 units (34.06 %) in Vessari, and 7.59 units (33.72 %) in Koli I. These localities were associated with local pine series which had standard deviations for

Table 11. Standard deviation of the indices for Scots pine stand series (upper figures), the number of years covered by the series (middle figures), and the number of sample trees (lower figures).

Plot No.	Ruotsinkylä	Punkaharju	Koli I	Koli II	Kaupinharju	Alkkia	Kaltila	Vessari	Hyytiälä
1	13.95 30 * 3	21.56 90 23	16.56 50 10	19.94 70 19	25.45 60 23	20.80 70 22	23.23 70 * 3	16.44 42 26	18.80 70 15
2	21.97 45 13	18.87 90 ** 10	19.50 50 11	17.70 50 20	25.06 50 * 3	18.87 40 18	28.39 70 * 4	24.93 42 * 2	22.51 70 * 3
3	13.20 30 14	23.23 90 ** 15	17.27 90 9	23.33 50 24	24.06 50 ** 13	22.60 70 22	16.12 70 26	15.18 42 ** 16	22.75 80 * 8
4	22.52 90 12	21.46 90 16	37.14 70 * 3	25.70 50 21	27.09 70 18	22.80 50 17	16.89 70 ** 8	18.85 42 26	22.05 70 18
5	23.37 90 10	27.30 90 * 5	22.57 70 13	21.79 70 * 2	21.64 30 * 9	17.22 30 25	17.12 70 ** 8		23.52 60 * 7
6	22.01 50 11	23.59 90 ** 11	22.86 90 19		18.61 70 ** 11	26.28 70 ** 19			18.12 90 25
7	12.22 36 ** 14	16.18 90 12	29.54 50 ** 12		25.85 70 18				14.36 50 20
8		18.08 90 12	21.97 50 14		15.20 30 ** 29				20.45 69 18
9		15.63 90 10	15.05 50 ** 15		48.71 50 * 2				20.80 69 * 5
10		21.10 90 10	21.41 90 17						16.18 59 21
11		22.30 90 12	23.36 50 17						17.94 69 ** 12
12		22.24 69 11							20.30 69 * 5
13		20.44 90 13							
Stand average	18.46	20.92	22.51	21.69	25.74	21.43	20.35	18.85	19.82
Local series	17.02	16.66	14.92	18.77	20.25	16.85	14.50	12.43	13.15
Difference	1.44	4.26	7.59	2.92	5.49	4.58	5.85	6.42	6.67
Difference, %	7.80	20.36	33.72	13.46	21.33	21.37	28.75	34.06	33.65

** Mixed stand with pine as dominant species.
* Mixed stand with other dominant species.

Table 12. Standard deviation of the indices for Norway spruce stand series (upper figures), the number of years covered by the series (middle figures), and the number of sample trees (lower figures).

Plot No.	Ruotsinkylä	Punkaharju	Laikko	Koli I	Koli II	Kaupinharju	Saarijärvi	Kaltila	Vessari	Hyytiälä
1	15.72	33.45	27.15	13.97	16.05	17.00	18.44	29.58	22.81	16.85
	30	90	70	40	90	50	70	70	42	70
	** 13	* 9	12	** 11	23	** 16	** 23	** 15	27	** 22
2	24.93	29.99	17.59	17.34	16.14	25.84	17.84	19.01	15.10	24.90
	50	50	70	50	90	50	70	70	42	80
	15	* 2	** 14	* 7	16	** 17	23	** 22	** 20	20
3	16.67	16.30	19.09	14.34	21.49	16.99	20.33	28.12	18.61	24.95
	30	50	70	60	80	50	70	70	42	80
	13	* 9	** 14	** 15	** 16	* 3	26	* 17	28	** 20
4	15.31	29.38	16.20	24.30	16.67	12.25	13.32	15.07	24.54	19.43
	70	70	70	60	30	50	70	70	42	70
	** 10	* 3	** 13	19	19	** 19	** 27	** 15	* 9	** 25
5	17.14		17.40		18.67	15.83				27.12
	30		70		90	50				80
	18		15		16	** 15				21
6	19.31		23.22		17.45	11.97				25.34
	42		70		90	40				60
	17		15		18	* 4				** 16
7	26.26		19.67		17.51	9.94				14.74
	50		70		90	20				60
	12		12		** 22	* 6				28
8	17.80		20.70		18.39					18.18
	62		70		40					70
	14		13		26					26
9	23.21				17.96					21.53
	50				70					69
	13				19					** 15
10	23.43				21.55					15.10
	35				50					69
	* 2				20					23
11	27.56									16.09
	70									69
	20									18
12										23.43
										69
										* 9
13										14.89
										69
										20
Stand average	20.71	27.28	20.13	17.49	18.19	15.76	17.48	22.95	20.27	20.20
Local series	16.47	26.53	14.47	13.59	13.16	11.38	14.74	16.68	17.86	14.01
Difference	4.24	0.75	5.66	3.90	5.03	4.38	2.74	6.27	2.41	6.19
Difference, %	20.47	2.75	28.12	22.30	27.65	27.79	15.68	27.32	11.89	30.64

** Mixed stand with spruce as dominant species.
* Mixed stand with other dominant species.

Table 13. Standard deviation between the indices for Scots pine stand and local series.

Locality	Annual index series[1]					5-year average series[2]					10-year average series[3]				
	s_1		s_2		Local series	s_1		s_2		Local series	s_1		s_2		Local series
	Min.	Max.	Min.	Max.	s_3	Min.	Max.	Min.	Max.	s_3	Min.	Max.	Min.	Max.	s_3
Ruotsinkylä	6.35	29.84	12.22	23.37	17.02	6.34	20.62	6.05	18.95	12.34	6.52	16.76	2.94	16.53	8.94
Punkaharju	3.91	23.04	16.18	27.30	16.66	3.97	18.34	9.68	24.92	11.92	5.65	14.99	4.91	23.03	8.46
Koli I	8.04	28.71	15.05	37.14	14.92	6.39	22.59	10.29	33.82	10.24	5.11	18.92	7.13	29.25	8.10
Koli II	5.32	26.41	17.70	25.70	18.77	4.98	19.03	11.60	21.63	13.54	4.32	15.58	6.96	17.31	9.31
Kaupinharju	10.19	36.03	15.20	48.71	20.25	7.81	25.86	5.89	40.10	15.47	6.73	19.15	2.42	27.44	12.67
Alkkia	5.93	33.03	17.22	26.28	16.85	4.67	21.60	9.86	23.29	12.24	5.60	14.35	7.06	20.27	9.35
Kaltila	3.85	47.15	16.12	28.39	14.50	4.21	32.23	12.01	22.56	10.38	4.22	22.39	9.46	19.09	9.50
Vessari	4.80	26.80	15.18	24.93	12.43	4.51	21.88	10.37	18.63	7.04	4.35	17.88	6.19	15.19	4.22
Hyytiälä	8.54	26.34	14.36	23.52	13.15	9.51	19.28	8.28	17.87	8.22	6.22	14.99	6.22	15.10	6.01
Average for local series					16.06					11.26					8.51

Table 14. Standard deviation between the indices for Norway spruce stand and local series.

Locality	Annual index series[1]					5-year average series[2]					10-year average series[3]				
	s_1		s_2		Local series	s_1		s_2		Local series	s_1		s_2		Local series
	Min.	Max.	Min.	Max.	s_3	Min.	Max.	Min.	Max.	s_3	Min.	Max.	Min.	Max.	s_3
Ruotsinkylä	9.21	21.21	15.31	27.56	16.47	6.52	15.96	8.03	22.20	11.33	6.35	11.34	5.42	18.75	7.46
Punkaharju	3.86	42.08	16.30	33.45	26.53	2.16	22.51	11.31	29.21	22.09	1.89	21.00	8.29	26.23	18.81
Laikko	3.99	26.78	16.20	27.15	14.47	5.86	23.02	10.91	21.58	8.76	5.50	19.39	8.04	19.15	6.15
Koli I	5.45	34.34	13.97	24.30	13.59	5.72	30.67	8.00	20.73	9.49	6.95	19.96	5.06	18.33	7.65
Koli II	7.70	19.39	16.05	21.55	13.16	6.62	13.67	11.14	18.89	9.38	5.58	10.75	5.94	17.18	7.49
Kaupinharju	6.32	21.51	9.94	25.84	11.38	5.56	15.04	5.76	20.61	6.41	4.62	9.25	2.94	16.44	4.38
Saarijärvi	2.22	21.95	13.32	20.33	14.74	1.26	15.69	7.46	16.78	10.77	1.15	12.82	5.72	14.88	9.13
Kaltila	5.25	35.32	15.07	29.58	16.68	5.32	25.38	9.45	26.41	13.55	3.30	23.21	6.82	23.76	11.85
Vessari	3.20	25.09	15.10	24.54	17.86	2.06	14.94	7.21	17.44	11.45	2.38	10.20	3.12	13.47	8.63
Hyytiälä	7.68	25.42	14.74	27.12	14.01	6.84	19.66	8.77	23.70	9.90	5.85	16.43	5.91	21.35	8.48
Average for local series					15.89					11.31					9.00

[1])

$$s_1=\sqrt{\frac{\sum_{i=1}^{n}(I_{ti}-\bar{I}_t)^2}{n-1}} \qquad s_2=\sqrt{\frac{\sum_{t=1}^{N}(I_{ti}-\bar{I}_i)^2}{N-1}} \qquad s_3=\sqrt{\frac{\sum_{t=1}^{N}(A_t-\bar{A})^2}{N-1}}$$

I_{ti} = the index of series i for year t,
$\bar{I}_t$ = the average index for year t,
n = the number of series.

$\bar{I}_i$ = the average index for series i,
N = the number of years in the series.

A_t = the local index for year t,
$\bar{A}$ = the average index for the local series.

[2]) The symbols in the formulae denote the corresponding figures for 5-year average index series.
[3]) The symbols in the formulae denote the corresponding figures for 10-year average index series.

Table 15. Variation of indices within the series in relation to size of the area.

Area	Scots pine			Norway spruce		
	Index series					
	Annual	5-year	10-year	Annual	5-year	10-year
	Standard deviation					
Locality Southern Finland	16.06 11.90	11.26 7.20	8.51 5.27	15.89 11.97	11.31 7.93	9.00 5.55
Difference Relative difference, % from locality	4.16 25.90	4.07 36.15	3.24 38.03	3.92 24.66	3.38 29.89	3.45 38.37

the indices of less than 15 units. The corresponding differences were 1.44 (7.80 %) in Ruotsinkylä, 2.92 (13.46 %) in Koli II, and 5.49 (21.33 %) in Kaupinharju (cf. Table 11). The differences were comparatively larger than those for spruce (see also Table 12).

The number of sample plots did not have any important effect on the magnitude of the standard deviation of the indices within local series, nor did it affect the difference between this standard deviation and the average standard deviation among stand series.

The standard deviation for the 5-year average indices of local pine series was about 4.8 index units or 36 % smaller than that of the annual indices, whereas the decrease was 7.6 index units or 47 % in the case of 10-year average index series. The corresponding figures were 4.6 units (or 30 %) and 6.9 units (or 45 %) for spruce.

The standard deviation of the indices within the series decreases successively with an increase in size of the area (*e.g.* from locality to southern Finland), as shown in Table 15.

4. APPLICATION OF THE RESULTS

41. Estimation of periodic growth

In utilizing the information on growth indices in growth estimation, 5-year average indices in this context, it had to be assumed that the climatic variation in the volume growth is approximately proportional to that of radial growth. It was also assumed that mortality and the changes in stem form did not significantly interfere with the relationship between volume and radial growth.

The analysis in this section was mainly concerned with the errors in the estimation of periodic growth in a locality, assuming that no information on growth indices was available. The periods for which the growth was estimated were *past period* and *future period*, referring respectively to growth as *past growth* and *future growth*. The growth features to be dealt with were *actual growth* and *average growth*. Actual growth in this connection referred to the growth in the existing climatic conditions, while average growth implied the growth corrected to the average level, *i.e.* to that indicated by the growth index 100.

The comparisons then dealt with the relative accuracy obtained using the following growth estimation methods:

1) The method based on stand characteristics (the application of stand functions),

2) The method based on the data from increment borings.

According to the investigation by NYYSSÖNEN and MIELIKÄINEN (1978), stand functions for volume increment percentage, having been corrected for climatic variation, derived from the data of 352 pine stands or 146 spruce stands using tree species, forest site type, stand age and volume as independent variables, yielded a standard error of the estimate of about 17 %. This did not include the error arising in the determination of independent variables. The corresponding standard error of the estimate in the study by GUSTAVSEN (1977), based on the sample plot data from the 3rd National Forest Inventory, was as high as 30 %. In this connection, the standard error of the estimate of 20 % is used in the further analysis, denoted by C in the following computations.

In estimating volume increment from stand measurements, the errors concerned are those arising in various measurements and estimations, *i.e.* of radial growth and height growth, and also from the use of increment tables for standing trees (*e.g.* tables prepared by ILVESSALO, 1948). In this case, the standard error in the estimation of volume increment of a stand, using 20–30 sample trees, was about ± 5–6 % (NYYSSÖNEN 1954, p. 157). In addition, STRAND (1958, p. 369–370) estimated the volume growth in 42 sample plots by employing different methods: regression estimator, sampling with probability proportional to size (PPS sampling), and stratified sampling with 5 cm diameter classes. He found that the average standard error in the estimation of volume increment by different methods, using 20 sample trees, ranged from 5.3 % to 6.6 %.

It was assumed from the results of these two studies, that the error in growth estimation based on the data from increment boring, denoted by D, was about 6 %.

It was also assumed that the trends in growth development were taken into account in the estimation of future growth. The trends in growth development are typically established in relation to stand age, volume, and mean diameter (*e.g.* as presented by NYYSSÖNEN and MIELIKÄINEN 1978, p. 16–18). It was assumed that these trends were estimated without error.

Two additional sources of errors still need to be mentioned.

1) The error due to climatic variation, denoted by A, which was defined by the standard deviation of the indices (5-year average indices) of local series (cf. Tables 13 and 14).

2) The deviation of future growth from past growth, denoted by B, which was defined by the magnitude of the standard deviation of the differences between the indices of future and past periods in a local series (cf. Equation 9). This error was subjected to the method of future growth estimation based on growth during the past period.

The errors occurring in the estimation of the growth of pine stands in different cases are shown in Table 16 and for spruce in Table 17.

As far as actual growth was concerned, the total error variance occurring in the estimation of past and future growth by applying the stand function was the sum of the error variance yielded by the function (C^2) and the error variance due to climatic variation (A^2). In the method based on the data from increment boring, the error in the estimation of past growth was equal to the measurement error only (ca. 6 %), while the total error in the case of future growth estimation was the sum of measurement error and the deviation of future growth from past growth.

With regard to average growth, the growth figures determined by stand function represented the average level of both past and future growth. Therefore, the total error in this connection was equal to the error yielded by the function only (ca. 20 %). The estimation of past and future average growth based on the data from increment boring was associated with the measurement error and the error due to climatic variation.

If the data on growth indices for southern Finland only were available, the following figures would have to be taken into account.

1) The climatic variation in the growth indicated by the standard deviation of the 5-year average indices for the series for southern Finland, denoted by E in the following computation. The variation accounted for 7.20 % in the case of pine (cf. Table 13) and 7.93 % for spruce (cf. Table 14).

2) The deviation of future growth from past growth, denoted by F, which was defined by the magnitude of the standard deviation of the differences between the indices for future and past periods in the series for southern Finland: 10.09 % for pine and 11.51 % for spruce.

The errors associated with the growth estimation methods were determined as follows.

1) The error due to climatic variation, denoted by X, was the difference between the standard deviation of the indices for the local series (as formerly defined by A) and that of the series for southern Finland (E as mentioned earlier).

2) The error which stemmed from the assumption that future growth would be at the same level as past growth, denoted by Y, was the difference between the standard deviation of the differences in the indices of future and past periods in local series (B) and that found in the series for southern Finland (F).

The errors concerning growth estimation, when the average growth indices for southern Finland were available, are also presented in Tables 16 and 17 for pine and spruce respectively.

As growth estimation is more often concerned with figures for the average level of growth, comparison of growth estimation methods was also made for large forest areas or a group of stands.

If the accuracy of estimation is the criterion, then the number of stands could be determined by the equation:

$$n = \left(\frac{s}{s_e}\right)^2,$$

where n equals the number of stands, s the error occurring in the estimation of average growth by a given method (cf. Tables 16 and 17), and s_e the allowable standard error of the estimate.

To facilitate this computation, it was essential to assume that there be no bias and that the systematic error occurring in ring measurement be avoided.

Using the data from Tables 16 and 17, 9 stands would be required in the stand function method compared with 4 stands in the method with increment boring in order to keep the allowable standard error of the estimate at the level of ± 7 %, or 45 and 18 stands by the respective methods for ± 5 % standard error.

However, it must be kept in mind that such a computation was made for comparative study only. In practice, the results would be less meaningful, since the growth estimation is in fact carried out on a different combination of sample trees.

Table 16. Standard error of estimate in the assessment of the increment of Scots pine stands.

Source of error	Locality									
	Ruotsinkylä	Punkaharju	Koli I	Koli II	Kaupinharju	Alkkia	Kaltila	Vessari	Hyytiälä	Average
	Error, %									
NO GROWTH INDICES AVAILABLE										
(1) Climatic variation, A	12.34	11.92	10.24	13.54	15.47	12.24	10.38	7.04	8.22	11.26
(2) Deviation of future growth from past growth, B	17.67	18.28	14.01	18.54	17.52	14.10	8.71	10.31	10.91	14.45
ACTUAL GROWTH										
Past growth										
(3) Based on stand function, $\sqrt{A^2+C^2}$	23.50	23.28	22.47	24.15	25.28	23.45	22.53	21.20	21.62	22.95
(4) Based on increment boring, D	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Future growth										
(5) Based on stand function = (3)	23.50	23.28	22.47	24.15	25.28	23.45	22.53	21.20	21.62	22.95
(6) Based on increment boring, $\sqrt{B^2+D^2}$	18.66	19.24	15.24	19.49	18.52	15.32	10.58	11.93	12.45	15.65
AVERAGE GROWTH										
Past and future growth										
(7) Based on stand function, C	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
(8) Based on increment boring, $\sqrt{A^2+D^2}$	13.72	13.34	11.87	14.81	16.59	13.63	11.99	9.25	10.18	12.76
AVERAGE GROWTH INDICES FOR SOUTHERN FINLAND AVAILABLE										
(9) Climatic variation, $X=\sqrt{A^2-E^2}$	10.02	9.50	7.28	11.47	13.69	9.90	7.48	1.51	3.97	8.66
(10) Deviation of future growth from past growth, $Y=\sqrt{B^2-F^2}$	14.51	15.24	9.72	15.55	14.32	9.85	5.09	2.12	4.15	10.34
ACTUAL GROWTH										
Past growth										
(11) Based on stand function, $\sqrt{C^2+X^2}$	22.36	22.14	21.28	23.06	24.24	22.32	21.35	20.06	20.39	21.79
(12) Based on increment boring, D	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Future growth										
(13) Based on stand function = (11)	22.36	22.14	21.28	23.06	24.24	22.32	21.35	20.06	20.39	21.79
(14) Based on increment boring, $\sqrt{D^2+Y^2}$	15.70	16.38	11.42	16.67	15.53	11.53	7.87	6.36	7.30	11.95
AVARAGE GROWTH										
Past and future growth										
(15) Based on stand function, C	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
(16) Based on increment boring, $\sqrt{D^2+X^2}$	11.68	11.24	9.43	12.94	14.95	11.58	9.59	6.19	7.19	10.54

Table 17. Standard error of estimate in the assessment of the increment of Norway spruce stands.

Source of error	Ruotsinkylä	Punkaharju	Laikko	Koli I	Koli II	Kaupinharju	Saarijärvi	Kaltila	Vessari	Hyytiälä	Average
	Error, %										
NO GROWTH INDICES AVAILABLE											
(1) Climatic variation, A	11.33	22.09	8.76	9.49	9.38	6.41	10.77	13.55	11.45	9.90	11.31
(2) Deviation of future growth from past growth, B	17.86	26.87	11.60	11.50	13.19	10.19	10.47	14.39	15.13	12.69	14.39
ACTUAL GROWTH											
Past growth											
(3) Based on stand function, $\sqrt{A^2+C^2}$	22.99	29.80	21.83	22.14	22.09	21.00	22.72	24.16	23.05	22.34	22.98
(4) Based on increment boring, D	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Future growth											
(5) Based on stand function=(3)	22.99	29.80	21.83	22.14	22.09	21.00	22.72	24.16	23.05	22.34	22.98
(6) Based on increment boring, $\sqrt{B^2+D^2}$	18.84	27.44	13.04	12.97	14.49	11.83	12.07	15.59	16.28	14.04	15.59
AVERAGE GROWTH											
Past and future growth											
(7) Based on stand function, C	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
(8) Based on increment boring, $\sqrt{A^2+D^2}$	12.82	13.50	10.62	11.23	11.13	8.78	12.33	14.82	12.93	11.58	12.80
AVERAGE GROWTH INDICES FOR SOUTHERN FINLAND AVAILABLE											
(9) Climatic variation, $X=\sqrt{A^2-E^2}$	8.09	20.62	3.72	5.21	5.01	4.67	7.29	10.99	8.26	5.93	8.06
(10) Deviation of future growth from past growth, $Y=\sqrt{B^2-F^2}$	13.66	24.28	1.44	0.48	6.44	5.35	4.78	8.67	9.82	5.34	8.64
ACTUAL GROWTH											
Past growth											
(11) Based on stand function, $\sqrt{C^2+X^2}$	21.57	28.73	20.34	20.67	20.62	20.54	21.29	22.82	21.64	20.86	21.56
(12) Based on increment boring, D	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Future growth											
(13) Based on stand function =(11)	21.57	28.73	20.34	20.67	20.62	20.54	21.29	22.82	21.64	20.86	21.56
(14) Based on increment boring, $\sqrt{D^2+Y^2}$	14.92	25.01	6.17	6.02	8.80	8.04	7.67	10.54	11.51	8.03	10.52
AVERAGE GROWTH											
Past and future growth											
(15) Based on stand function, C	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
(16) Based on increment boring, $\sqrt{D^2+X^2}$	10.07	21.48	7.06	7.95	7.82	7.60	9.44	12.52	10.21	8.44	10.05

42. Number of sample trees required for computing the index series

421. Series for southern Finland

As the growth rhythms of the pooled series were very similar (illustrated by visual comparison), it is obvious that a relatively small number of sample trees can satisfactorily determine the growth rhythm of trees in southern Finland.

The results of a comparison between the 5-year moving average indices for a pooled series (cf. Section 234) and the series for southern Finland (based on annual ring indices presented in Figs. 4 and 5) are shown in Table 18. The standard deviation for the differences decreased successively with an increase in sample size when the comparison was made for the longest period (1914–1977). Some irregularity became evident in the shorter periods. It is to be noted that the standard deviation for the differences for Alternative 7 (total material) is not zero, since the comparisons were made using the series for southern Finland as a basis.

Referring to the data presented in Table 2, the average standard deviation between the local index series, s_1, was equal to 11.67 for pine, and 11.90 for spruce (cf. Table 3): the subsequent standard error being $11.67/\sqrt{9}=3.89$ and $11.90/\sqrt{10}=3.76$ respectively.

The present results suggest that the index series for southern Finland could be constructed, with standard error of about 3.5 % for 5-year moving average indices, using the following samples:

1) The data collected from about 10 localities with geographically reasonable distribution.

2) The data collected from each locality by two relascope plots with BAF 1 or 2. In this way, it would be possible to measure one locality in one working day, the number of sample trees being as many as 40 to 50 trees by two-man team.

Table 18. Deviation in 5-year average indices for the pooled series as compared to the series for southern Finland.

Alternative	Number of plots	Number of trees	Period				
			1958–77	1948–77	1938–77	1928–77	1914–77
			Deviation from the series of local average[1])				
	Scots pine						
3	17	80	4.72	5.25	5.02	4.54	4.58
6	14	332	2.37	2.84	2.70	2.75	4.38
2	23	273	5.71	4.78	4.36	4.10	4.24
4	40	348	4.18	3.53	3.81	3.67	3.88
1	39	525	3.09	2.63	2.34	2.13	2.85
5	55	605	2.76	2.29	2.03	1.97	2.12
7	69	937	1.86	1.66	1.46	1.37	1.75
	Norway spruce						
3	10	54	3.53	5.01	4.83	9.82	12.94
4	23	218	2.39	2.67	2.92	3.62	5.14
2	17	288	1.87	2.44	2.90	3.42	4.15
6	20	469	3.34	2.92	3.83	3.67	3.70
5	44	566	0.95	1.08	1.80	2.20	3.27
1	33	549	1.60	2.20	2.20	2.14	2.26
7	64	1035	1.18	1.24	1.30	1.41	1.66

[1]) Deviation (in index units) as determined by Equation (8).

Table 19. Deviation in 5-year average indices for the local series computed from different numbers of sample trees as compared to the series with all the sample trees in that locality.[1])

Series	Number of plots	Number of trees	Period 1958–77	1948–77	1938–77	1928–77	1914–77
			Deviation from local series[2])				
Punkaharju, Scots pine							
1	2	20	6.20	6.42	5.69	6.60	8.04
2	3	25	9.06	8.96	8.57	8.18	9.21
3	4	35	6.52	6.42	5.97	5.81	6.71
4	5	46	5.01	4.51	4.26	3.97	4.13
5	4	48	4.86	4.21	4.25	4.11	5.34
6	7	82	1.95	1.73	1.67	2.01	3.25
Koli, Scots pine							
1	2	27	10.95	9.94	9.17	8.50	7.81
2	4	39	5.72	4.73	5.78	8.42	9.06
3	5	51	6.22	5.42	5.99	8.23	8.14
4	6	65	4.25	3.68	3.81	6.58	6.64
5	6	85	5.17	4.37	3.86	3.73	3.59
6	7	82	2.58	2.82	3.50	3.48	3.64
7	10	123	1.48	1.30	1.68	2.64	2.33
Hyytiälä, Norway spruce							
1	2	36	8.79	9.47	8.94	9.59	11.21
2	2	50	7.41	6.68	7.05	8.81	9.43
3	3	62	5.05	5.30	5.23	5.41	7.17
4	4	87	3.97	3.89	3.50	3.49	4.79
5	4	91	2.89	2.81	2.52	2.46	3.91
6	4	99	3.15	2.97	2.90	3.89	4.83

[1]) Total number of sample trees: Punkaharju 157, Koli 140, Hyytiälä 178.
[2]) Deviation (in index units) as determined by Equation (8).

422. Local series

If the study is carried out locally, a construction of series for southern Finland is not necessary. In this case, the number of sample plots per locality must be increased.

Table 19 illustrates the comparison between local series (as computed from different numbers of plots and trees) using the same procedure as used in Table 18. The three series with the smallest samples yielded the standard deviation for the differences which were larger than 5 index units. This can be regarded as a distinct underestimate of the error, due to the fact that local series including all sample trees also possesses an error component.

The standard deviations between the stand series were studied in Punkaharju, Koli, and Hyytiälä. The results are as follows:

	Standard deviation between stand series	No. of series	Standard error for locality
Punkaharju, pine	14.48	13	4.02
Koli, pine	16.66	11	5.02
Hyytiälä, spruce	15.09	8	5.34

The results reveal that the annual ring index series from Punkaharju, Koli, and Hyytiälä determine the growth figures for trees in the corresponding locality fairly well. If the standard error is allowed to be at the level of ± 5%, the data from 9 sample plots would certainly be sufficient for computing the local index series for Punkaharju, as well as 12 plots in Koli and 10 plots in Hyytiälä.

In accordance with the results mentioned above, the data from 10 relascope plots are sufficient in the study of climatic variation in tree growth in a particular locality. This subsequently means that 150–200 sample trees would be included. It is therefore recommended that the error of ±5 % be added to the errors occurring in the growth estimation based on growth indices.

5. DISCUSSION

The growth rhythm of Scots pine in different localities was rather similar during certain periods, especially in the years when a very high or very low growth rate prevailed. However, pine in southern Finland exhibited east-west differentiation in growth during the first 20-year period and the last 15-year period in the series. During the years 1910 to 1929, trees in eastern localities demonstrated greater variation in growth compared with those in western localities. The growth rhythm in different localities was very similar during the middle period of the series, especially during the 1930's and 1950's. The east-west differentiation in growth again became apparent in the 1960's when variation in growth was higher in the east, especially during the end of that decade (cf. Tables 2 and 4, Fig. 2).

According to the present study, spruce also exhibited east-west differentiation in growth in southern Finland, especially during the last 20 years (cf. Table 3 and Fig. 3). The variation in the indices was obviously greater in western localities. This was in contrast to that which had been found with pine, the variation in the indices being greater in the east. The result illustrated the dissimilarity in the growth pattern of pine and spruce growing in the same region.

It was evident that the southernmost locality, Ruotsinkylä, can be regarded as a transitional zone as regards the growth performance of pine and spruce; pine in Ruotsinkylä belonged to the eastern region, while spruce exhibited the growth pattern of the western group.

Although very clear differences in the growth rhythm could be distinguished in some years, the differences between local series were nonsignificant. The differences between calendar years were highly significant (cf. Table 5).

Silvicultural treatment, such as cutting and fertilization, is known to have an effect on radial growth. However, such an effect was diminished in the present results when different stand series were combined to represent the local series. This was confirmed by the results of analysis of variance which showed that there were significant differences between stand series, but not between local series. Similar results were also obtained when the comparison was made between pooled series (cf. Table 8). Combining the index series for untreated stands only may also reduce the variation in the indices, since the difference between stand indices might be very large in particular years.

The correlation between local series seemed to be independent of the number of sample trees in each locality. The pine series computed from only a few sample trees (*e.g.* Laikko and Saarijärvi) matched each other surprisingly well, but correlated poorly with other localities. The rather good correlation which was found between the series for Saarijärvi in the west and the series for Laikko and Punkaharju in the east must be regarded as a random event.

Seven pooled series were computed from the data obtained by alternative methods (with different number of sample trees) of sample plot selection. The sample plots for each alternative were selected systematically by plot number or the number of sample trees in the plots. Therefore, all conclusions drawn from this analysis applied to the conditions existing in this investigation only. It was found, however, that even the pooled series computed from less than 10 per cent of the total number of sample trees was in good agreement with the series for southern Finland, as far as the growth rhythm was concerned (cf. Figs. 4 and 5). The study of growth magnitude, however, actually requires many more sample trees.

The growth rhythm of the two groups of material gathered in two successive years (from Hyytiälä) was very similar, but the level of growth indices was in general slightly different. However, it was apparent that the difference in the growth indices of pine had clearly been greater since the beginning of the 1960's, as compared to that for spruce indices.

The differences between the two index series for pine during the above-mentioned period were also very clear for the 5-year and 10-year moving average indices. The corresponding indices for spruce were quite similar. This outcome may be partly due to the different nature of the growth response of pine and spruce, since spruce is known to be more sensitive in its annual growth, while long-term growth variations are more marked in pine (MIKOLA 1950).

Since it was found that the differences between the local series were nonsignificant, it was of no surprise that the difference between two local series for Hyytiälä was nonsignificant, too. These two series were closely correlated to each other within any period, ranging from 10- to 60-year periods. The correlation was higher for spruce than for pine. It should be kept in mind that the differences between two series may change as the time lag between sampling increases.

The annual ring index series presented in this study was in very good agreement with those series based on the data from the 3rd and the 6th National Forest Inventory, *i.e.* the data from natural stands. The standard deviation of the differences was about 5.5 index units for pine, while for spruce series it ranged from 5.6 to 9.3 index units. The variation was obviously smaller than that between the two series for Hyytiälä. According to the present comparisons, it would be sufficiently reliable to use the data from regularly-treated stands for computing the annual ring index series for southern Finland. By careful selection of sample stands, the effect of stand treatment will be reduced when combining stand series to form the local series, and the subsequent series to form that of southern Finland.

The variation in growth between stands in a single year can be very large. The combination of annual ring index series for different stands always reduces the diversity of annual growth. Hence, the variation in the indices for the local series was smaller than that for stand series, and variation in the indices for the series for southern Finland was subsequently smaller than that found in the local series (cf. Tables 11–15).

Pine and spruce seemed to respond differently to the same degree of change in growth factors, *i.e.* a good year for growth of pine, as indicated by annual ring indices, may not necessarily be a good year for spruce (cf. Figs. 2 and 3). Consequently, the index series have to be constructed separately for each tree species, also for a mixed stand.

In the present investigation, the standard deviation of the annual ring indices for the local pine series was reduced by 4.8 index units (36 %) when the series of 5-year moving average indices were computed, and 7.6 index units (47 %) in the case of 10-year moving average indices. The corresponding reductions in the case of spruce were 4.6 and 6.9 index units (30 % and 45 % respectively).

When the local pine series were combined for the series for southern Finland, the reduction in the standard deviation was 26 % for annual ring index series, 36 % and 38 % for 5-year and 10-year moving average index series respectively. The decrease in the variation found in the annual and 5-year average index series for spruce was smaller than that for pine, *i.e.* 25 % and 30 %, although in the case of 10-year average indices it was of the same magnitude, 38 %.

The information about the variation in growth indices within the series, local series and the series for southern Finland as a whole, is very useful in the growth estimation. This variation represents the magnitude of climatic fluctuations which must be taken into account when the growth estimation is to be carried out.

In the absence of information about growth indices, the total error in the estimation of the actual growth of pine stands for the past period by the method involving increment boring is apparently very much smaller than that given by the stand function method (*e.g.* 6 % in comparison to 23 %, on an average for the localities). The differences between these errors for future growth estimation was smaller, since the error stemmed from the assumption that future growth, maintained at the same level as growth during the past period, was added to the measurement error in order to represent the total error yielded by the method involving increment boring. Under this assumption, the error might be rather large, even larger than the error due to climatic variation. However the accuracy of the method involving increment boring proved this assumption to be applicable for future growth estimation (*e.g.* the error of 16 % compared with that of 23 % given by the stand function method).

Although the error due to climatic variation was added to the measurement error, the total error in estimating the average growth by the method involving increment boring was still obviously smaller than that given by the stand function method (*e.g.* 13 % in comparison to 20 %). The errors found in all the localities proved that the method involving increment boring was apparently superior to the application of a stand function.

With regard to the localities, the errors in growth estimation given by the method involving increment boring were found to be larger in eastern Finland than those found in western localities. This was pertinent to the earlier results: variation in the growth of pine was larger in the eastern region.

By assuming that the index series for southern Finland would be available, the accuracy of the estimation of actual growth by means of the stand functions was improved only very slightly (*e.g.* the error of 22 % compared with 23 % given by the estimation not including any information on growth indices). On the other hand, the accuracy in future growth estimation by the method involving increment boring was imporoved noticeably (*e.g.* error of 12 % compared with 16 %). Although the range of errors in this connection was not very large, it might mean a great difference in cubic volume when the estimation is carried out on large forest areas.

With regard to comparison with the method of growth estimation, the use of available average growth indices for southern Finland in future growth estimation placed more weight on the superiority of the method involving increment boring over the stand function method. The total error given by the method involving increment boring was only 12 % compared with 22 % for the stand function method.

Even though the errors in estimating the growth of spruce stands for different cases were comparatively different from those of pine stands from the same locality, the average values were rather similar (cf. Tables 16 and 17). It was earlier observed that the growth of pine and spruce in the same locality was somewhat different: the accuracy of growth estimation in this connection was thus different. It was also found in eastern Finland that the variations in the indices for stand and local series of pine were larger than those of spruce, while the opposite phenomenon was found in western Finland. Hence, the average values from all localities representing growth variation in pine and spruce were similar, and the accuracy of the growth estimation was therefore almost the same.

It could subsequently be concluded that the method of growth estimation which included data from increment boring was in most cases superior to the stand function method, assuming the trend in growth development as a function of time is known. However, it must be borne in mind that including increment boring means more work and, consequently, additional costs to be incurred. In practice, not only the accuracy but aldo other factors, such as the purpose of estimation, time and costs, must be taken into consideration in evaluating, the growth estimation methods.

The data from increment boring have appeared to be useful for growth estimation. Such data, even from a small number of samples, naturally represent the climatic variation in the growth of trees from which growth during the past period can be measured and the future growth estimated.

The accuracy of future growth estimation can be substantially improved by including the data on average growth indices (for southern Finland in the present study) in the computation. Such average growth indices will become quite commonly available in the future, *i.e.* from extensice material gathered in conjunction with the National Forest Inventory, of from specific growth investigations. The emphasis must also be placed on the improvement of the reliability of the average growth indices in representing the climatic variation in the growth of trees and stands.

Since untreated stands are becoming increasingly scarce, treated stands are more and more used in the study of the effects of the climatic variation on the growth of trees and stands. Apart from the investigations on mortality and changes in stem form, futher studies are needed to clarify the combined effects of climate and stand treatment. When such information becomes available, in both quality and quantity, the average growth index series can be established for use in growth estimation in different cases.

6. SUMMARY

Variation in the radial growth of Scots pine and Norway spruce was studied in 10 localities in southern Finland. The aim of the study was to utilize the information on variation in the growth indices for growth estimation, and to evaluate the relative accuracy of growth estimation based on the data from increment boring, in comparison to other methods.

The relascope plot techique was employed in sample tree selection. One increment core was taken from each sample tree at breast height. The final number of sample trees utilized in this study was 2118, 998 of which were pine and 1120 spruce. The cores were measured and the data processed at the Department of Forest Mensuration and Management of the University of Helsinki.

The normal radial growth (ring width) for different calendar years was computed for each plot by means of a hyperbolic function derived from the relationship between ring widths of all sample trees in a plot and age in the corresponding years. Standardization of ring widths was made for each sample plot. The indices for local series were determined by sequentially averaging the indices for stand series (weighted by the number of sample trees in the plots) within that locality. The index series for southern Finland was formed as a sequence of arithmetic means for the local indices for each calendar year. The 5-year average index for a given year was the arithmetic mean of the annual ring index for that year and the indices for the 4 preceding years. The 10-year average index was represented by the arithmetic mean of the index for a given year and those for the 9 preceding years.

There was no significant difference between the annual ring indices for local series of pine or spruce. A significant difference was found between the indices for stand series in some localities. The difference between the indices for different calendar years was found to be highly significant in most cases.

The variation in the annual ring indices for the local series (as expressed by standard deviation) ranged from 12 % to 20 % in pine and 11 % to 27 % in spruce, compared with the corresponding values of 7 % to 15 % and 6 % to 22 % repectively in the case of 5-year average indices. The variation in annual ring indices was reduced by 20 % to 30 % when the stand series were combined to form the local series, and also by 25 % when the series for southern Finland was computed from different local series. The decrease was larger for pine than for spruce.

East-west differentiation in the growth performance of trees was reflected in the growth rhythm, by the variation in the indices for stand and local series, and by the accuracy of growth estimation. Variation in the indices for pine in eastern Finland was larger than that in the west, while the variation was larger in western localities in the case of spruce. With regard to tree species, the variation in the indices for pine series was larger than that of spruce series in eastern Finland, whereas the variation in the indices for the spruce series was larger in western localities.

The annual ring index series for southern Finland presented in this study was in very good agreement with those series based on the data from the 3rd and the 6th National Forest Inventory. Therefore, the index series computed mainly from the data from regularly-treated stands could represent the growth features of trees in southern Finland just as well as the data from natural stands.

When the growth estimation was assumed to be carried out without any information on growth indices, the standard error of the estimate in the estimation of actual growth for past and future periods by the stand function method was about 23 %. For the method involving increment boring, the error accounted for 6 % and 16 % respectively in the estimation of past and future growth. The error in the estimation of average growth for both past and future periods by the stand function method was about 20 %, compared with that of 13 % for the method involving increment boring.

By employing the average growth indices for southern Finland in the local growth estimation, the accuracy of the stand function method was insignificantly improved. In

contrast, the accuracy in estimating actual growth for the future period by the method involving increment boring was distinctly improved. The error in this case was equal to 12 % only, compared with 16 % as mentioned above. Some improvement could be achieved also in the estimation of average growth (by the method involving increment boring) through the utilization of the average growth indices for southern Finland.

In conclusion, it seems to be justified to recommend the use of 10 localities in the computation of the index series for southern Finland; 10 sample plots for local series in the study of the climatic variation in tree growth in a given locality. The error of the growth series should be added to the errors occurring in growth estimation based on growth indices.

Further studies are needed to improve the reliability of the average growth index series representing the climatic variation in growth. Together with more information on mortality and changes in stem form, the accuracy of growth estimation can be improved accordingly. In the total evaluation of different methods of growth estimation, attention must be paid to the cost factors, too.

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SELOSTE

MÄNNYN JA KUUSEN SÄDEKASVUN ILMASTOLLINEN VAIHTELU JA SEN MERKITYS KASVUN ARVIOINNISSA

Männyn ja kuusen sädekasvun vaihtelua tutkittiin kymmeneltä Etelä-Suomen paikkakunnalta kerätyn aineiston avulla. Tavoitteena oli soveltaa kasvuvaihtelusta saatuja tietoja runkopuun tilavuuskasvun metsiköittäiseen arviointiin ja verrata kairauksiin perustuvien kasvunarviointimenetelmien tarkkuutta muiden menetelmien tarkkuuteen.

Koepuut valittiin metsiköistä relaskoopilla. Kustakin koepuusta kairattiin yksi lastu rinnankorkeudelta. Tutkittuja puita oli yhteensä 2118, joista mäntyjä 998 ja kuusia 1120. Kairanlastut mitattiin ja aineisto käsiteltiin Helsingin yliopiston metsänarvioimistieteen laitoksessa.

Normaalikasvut kalenterivuosille laskettiin koealoittain siten, että puiden vuotuiset sädekasvut tasoitettiin hyperbelimallilla, jossa selittävänä tunnuksena oli puun ikä. Kasvuindeksi laskettiin koealan puiden vuosilustojen keskiarvojen suhteesta kyseessä olevien vuosien normaalikasvuun. Näin saaduista metsikkökohtaisista indeksisarjoista päästiin aluekohtaisiin indeksisarjoihin laskemalla samaan alueeseen kuuluvista metsikkösarjoista kalenterivuosittaiset keskiarvot koepuiden lukumäärällä painotettuna. Indeksit koko Etelä-Suomelle saatiin aluekohtaisten sarjojen indeksiarvojen aritmeettisista keskiarvoista. Viiden vuoden liukuva keskiarvoindeksi laskettiin kyseisen vuoden ja sitä edeltäneiden neljän vuoden indeksien aritmeettisena keskiarvona. Samanlaista laskentatekniikkaa sovellettiin myös kymmenen vuoden liukuvan keskiarvon laskentaan.

Tutkimuksessa ei todettu merkitseviä eroja eri alueiden indeksisarjojen välillä. Sensijaan joidenkin alueiden metsikkösarjojen välillä merkitseviä eroja löydettiin. Vuotuisten indeksien väliset erot olivat useimmissa tapauksissa erittäin merkitseviä.

Aluesarjojen vuotuisten indeksien hajonta vaihteli 12 %:sta 20 %:iin männyllä ja 11 %:sta 27 %:iin kuusella. Vastaavat arvot viiden vuoden liukuville keskiarvoille olivat 7 % ja 15 % männyllä ja 6 % ja 22 % kuusella. Vuotuisten indeksien hajonta aleni 20–30 % yhdistettäessä metsikkösarjat aluesarjoiksi ja edelleen 25 %:lla, kun aluesarjat yhdistettiin Etelä-Suomen sarjaksi. Männyllä hajonta pieneni enemmän kuin kuusella.

Itä- ja Länsi-Suomen indekseissä oli havaittavissa pieniä eroja. Männyn indeksien vaihtelu oli suurempaa Itä-Suomessa ja kuusen indeksien Länsi-Suomessa. Männyn indeksit vaihtelivat enemmän kuin kuusen Itä-Suomessa ja kuusen indeksit enemmän kuin männyn Länsi-Suomessa.

Tässä tutkimuksessa saadut Etelä-Suomen sarjat sopivat erittäin hyvin yhteen valtakunnan metsien III ja VI inventoinnin aineistosta laskettujen sarjojen kanssa. Tämä osoitti, että aineistojen keruu hakkuin ym. käsitellyistä metsistä ei vaikuta kovin haitallisesti tuloksiin.

Kun jakson todellinen kasvu arvioitiin ilman kasvuindeksejä kasvufunktiolla, keskivirheeksi saatiin 23 %. Kairauksiin perustuvalla menetelmällä menneen ja tulevan kauden kasvuarvioiden keskivirheeksi saatiin 6 % ja 16 %. Keskimääräisen (ilmastovaihtelusta vapaan) kasvun arvioinnissa funktiolla päästiin 20 % keskivirheellä ja kairauksiin perustuvalla menetelmällä 13 % keskivirheellä.

Metsikön kasvufunktioiden antamien keskimääräistä kasvua osoittavien tulosten tarkkuutta voitiin parantaa vain vähän, kun Etelä-Suomen kasvuindeksit otettiin käyttöön. Sen sijaan kairauksiin perustuvassa tulevan jakson todellisen kasvun arvioinnissa kasvuindeksien käyttö paransi selvästi tarkkuutta. Näin saadun arvion virhe oli vain 12 %, kun se ilman indeksien käyttöä oli 16 %. Myös jakson keskimääräisen kasvun arviointitarkkuus parani jonkin verran, kun kairauksien lisäksi käytettiin hyväksi Etelä-Suomen ilmastoindeksejä.

Tutkimuksen mukaan vuotuisen indeksisarjan tarkkuuden saaminen vähintään 5 %:n tasolle näyttää edellyttävän, että Etelä-Suomen sarjoja varten aineisto kerätään 10 paikkakunnalta, jolloin kultakin paikkakunnalta mitattaisiin 2 relaskooppikoealaa. Aluekohtaista sarjaa varten sama tarkkuus edellyttäisi yhteensä 10 koealan mittaamista. Kasvusarjoihin liittyvän virheen vaikutus tulisi tietysti lisätä kasvuindeksien avulla saatujen kasvujen virhearvioon.

Ilmastovaihtelua osoittavien kasvuindeksisarjojen luotettavuuden lisäämiseksi tarvitaan lisää tutkimustyötä. Kasvunarvioinnin tarkkuus voisi parantua, kun poistuma ja muutokset runkomuodossa otetaan myös huomioon. Eri kasvunarviointimenetelmien lopullisessa vertailussa tulee luonnollisesti kiinnittää huomiota myös kustannustekijöihin.

APPENDICES

Appendix I. Material from Ruotsinkylä.

Plot No.	Forest site type	Dominant species	Average age at bh, years	Height, m	Mean diameter, cm	Number of sample trees			Remarks
						Pine	Spruce	Total	
1	OMT	Spruce	58	22	31.2	2	13	15	Cut 1960
2	OMT	Spruce	77	20	27.5	–	15	15	Cut 1960
3	OMT	Spruce	50	22	22.8	–	13	13	Cut 1953, 1963
4	MT	Spruce	103	24	29.0	1	10	11	Cut 1958, 1971
5	MT	Pine	67	26	28.8	13	–	13	Cut 1960
6	MT	Spruce	58	20	24.7	–	18	18	Cut 1965
7	OMT	Spruce	67	26	36.1	–	17	17	Cut 1960
8	MT	Spruce	90	22	28.1	–	12	12	Cut 1960
9	MT	Pine	53	22	29.9	14	–	14	Cut 1960
10	MT	Spruce	85	20	25.3	–	14	14	Cut 1960
11	OMT	Spruce	72	26	32.6	–	13	13	Cut 1959
12	CT	Pine	133	22	28.1	12	–	12	Cut 1954
13	CT	Pine	145	22	30.7	10	–	10	Cut 1954
14	CT	Pine	74	18	26.1	11	–	11	Cut 1947, 1969
15	MT	Pine	59	26	28.3	14	2	16	Cut 1956, 1967
16	MT	Spruce	173	32	38.3	–	20	20	Natural stand
Total						77	147	224	

Appendix II. Material from Punkaharju.

Plot No.	Forest site type	Dominant species	Average age at bh, years	Height, m	Mean diameter, cm	Number of sample trees			Remarks
						Pine	Spruce	Total	
1	VT	Pine	121	30	32.8	23	–	23	Natural stand
2	MT	Pine	140	28	37.1	10	9	19	–"–
3	MT	Pine	161	29	37.8	15	2	17	–"–
4	MT	Pine	134	30	39.3	16	–	16	–"–
5	OMT	Spruce	71	30	28.1	5	9	14	–"–
6	MT	Pine	140	27	39.8	11	3	14	–"–
7	MT	Pine	146	33	40.1	12	–	12	Tended stand
8	VT	Pine	152	29	41.9	12	–	12	–"–
9	VT	Pine	119	29	38.7	10	–	10	–"–
10	VT	Pine	153	30	42.1	10	–	10	–"–
11	VT	Pine	126	26	33.8	12	–	12	–"–
12	VT	Pine	147	26	36.7	11	–	11	–"–
13	VT	Pine	128	27	38.9	10	–	10	–"–
Total						157	23	180	

Appendix III. Material from Laikko, Simpele.

Plot No.	Forest site type	Dominant species	Average age at bh, years	Height, m	Mean diameter, cm	Number of sample trees			Remarks
						Pine	Spruce	Total	
1	MT	Spruce	129	28	31.6	–	12	12	Natural stand
2	MT	Spruce	128	36	37.9	–	14	14	– " –
3	MT	Spruce	136	26	39.0	2	14	16	– " –
4	MT	Spruce	113	24	34.4	1	13	14	– " –
5	MT	Spruce	107	26	33.7	–	15	15	– " –
6	MT	Spruce	114	29	35.9	–	15	15	– " –
7	MT	Spruce	126	22	30.1	–	12	12	– " –
8	MT	Spruce	124	26	30.9	–	13	13	– " –
Total						3	108	111	

Appendix IV. Material from Koli I (south).

Plot No.	Forest site type	Dominant species	Average age at bh, years	Height, m	Mean diameter, cm	Number of sample trees			Remarks
						Pine	Spruce	Total	
1	VT	Pine	75	19	22.0	10	–	10	Cut 1952, 1963
2	CT	Pine	69	18	25.6	11	–	11	Cut 1952, 1963
3	VT	Pine	133	23	19.6	9	–	9	Cut 1950, 1962
4	MT	Spruce	59	23	34.8	3	11	14	Cut 1951, 1962
5	VT	Pine	102	24	33.9	13	–	13	Cut 1951, 1972
6	VT	Pine	70	18	25.0	19	–	19	Cut 1951, 1959
7	MT	Pine	66	26	31.5	12	7	19	Cut 1952, 1963
8	MT	Spruce	92	20	28.6	–	15	15	Cut 1952, 1963
9	VT	Pine	70	22	21.9	14	–	14	Cut 1952, 1963
10	MT	Pine	69	18	26.5	15	–	15	Cut 1952, 1963
11	VT	Pine	146	25	35.0	17	–	17	Cut 1951, 1962
12	VT	Pine	79	16	26.4	17	–	17	Cut 1951, 1960
13	OMT	Spruce	111	28	35.6	–	19	19	Cut 1953, 1961, 1969
Total						140	52	192	

Appendix V. Material from Koli II (north).

Plot No.	Forest site type	Dominant species	Average age at bh, years	Height, m	Mean diameter, cm	Number of sample trees			Remarks
						Pine	Spruce	Total	
1	VT	Pine	117	18	27.4	19	–	19	Natural stand
2	OMT	Spruce	104	28	40.6	–	23	23	Natural stand
3	MT	Spruce	121	24	27.9	2	16	18	Cut 1955, 1970
4	OMT	Spruce	116	26	40.1	–	16	16	Cut 1955, 1970
5	VT	Pine	77	20	24.2	20	–	20	Cut 1954, 1970
6	OMT	Spruce	58	22	27.6	–	19	19	Cut 1954, 1970
7	OMT	Spruce	141	32	37.7	–	16	16	Cut 1954, 1970
8	MT	Spruce	135	28	39.6	–	18	18	Cut 1954, 1966
9	MT	Spruce	110	21	29.0	–	22	22	Cut 1953, 1966
10	OMT	Spruce	69	24	26.5	–	26	26	Cut 1953, 1969
11	VT	Pine	77	18	19.9	24	–	24	Cut 1953, 1965
12	VT	Pine	84	17	23.2	21	–	21	Cut 1953, 1966
13	MT	Spruce	102	28	38.2	–	19	19	Cut 1957
14	OMT	Spruce	73	27	37.6	–	20	20	Cut 1957, 1971
Total						86	195	281	

Appendix VI. Material from Kaupinharju, Rautalampi.

Plot No.	Forest site type	Dominant species	Average age at bh, years	Height, m	Mean diameter, cm	Number of sample trees			Remarks
						Pine	Spruce	Total	
1	VT	Pine	92	19	26.9	23	–	23	Uncut
2	OMT	Spruce	75	24	35.2	2	16	18	– " –
3	OMT	Spruce	77	28	35.9	3	17	20	– " –
4	MT	Pine	85	26	30.3	13	3	16	– " –
5	OMT	Spruce	72	28	37.4	–	19	19	– " –
6	VT	Pine	123	19	30.4	18	–	18	– " –
7	MT	Spruce	66	22	29.4	9	15	24	– " –
8	MT	Pine	101	22	31.0	11	4	15	– " –
9	CT	Pine	100	17	28.7	18	–	18	– " –
10	OMT	Pine	63	24	28.9	29	6	35	– " –
Total						126	80	206	

Appendix VII. Material from Alkkia and Saarijärvi.

Plot No.	Forest site type	Dominant species	Average age at bh, years	Height, m	Mean diameter, cm	Number of sample trees			Remarks
						Pine	Spruce	Total	
Alkkia, Karvia									
1	CT	Pine	95	18	23.2	22	–	22	Cut 1961, 1975
2	CT	Pine	69	18	23.2	18	–	18	Cut 1966, 1975
3	CT	Pine	93	16	19.7	22	–	22	Cut 1960
4	CT	Pine	69	16	16.8	17	–	17	Cut 1960
5	VT	Pine	46	14	15.5	25	–	25	Cut 1960
6	VT	Pine	107	19	24.3	19	–	19	Cut 1957
Total						123	–	123	
Saarijärvi, Parkano									
1	MT	Spruce	90	24	24.9	–	23	23	Uncut
2	MT	Spruce	99	21	26.9	–	23	23	– " –
3	MT	Spruce	114	22	26.8	–	26	26	– " –
4	OMT	Spruce	111	30	35.4	10	27	37	– " –
Total						10	99	109	

Appendix VIII. Material from Kaltila and Vessari.

Plot No.	Forest site type	Dominant species	Average age at bh, years	Height, m	Mean diameter, cm	Number of sample trees			Remarks
						Pine	Spruce	Total	
Kaltila, Kuorevesi									
1	MT	Spruce	113	26	31.8	3	15	18	Cut 1953, 1965
2	MT	Spruce	121	26	31.2	4	22	26	Cut 1949
3	CT	Pine	105	22	28.1	26	–	26	Cut 1951
4	MT	Spruce	124	25	23.9	8	17	25	Cut 1951
5	MT	Spruce	108	26	29.2	8	15	23	Cut 1969
Total						49	69	118	
Vessari, Ruovesi									
1	MT	Spruce	65	26	26.0	–	27	27	Cut 1958
2	VT	Pine	60	24	24.2	26	–	26	Cut 1958
3	MT	Spruce	74	25	27.0	2	20	22	Cut 1952
4	OMT	Spruce	61	25	24.3	–	28	28	Cut 1959
5	MT	Pine	58	25	27.9	16	9	25	Cut 1958, 1959
6	MT	Pine	74	24	27.0	26	–	26	Cut 1952
Total						70	84	154	

Appendix IX. Material from Hyytiälä, Helsinki University Field Station. Plots 1–12, data collected in 1978; plots 13–19, data collected in 1979.

Plot No.	Forest site type	Dominant species	Average age at bh, years	Height, m	Mean diameter, cm	Number of sample trees			Remarks
						Pine	Spruce	Total	
1	VT	Pine	107	22	27.8	15	–	15	Fertilized 1971
2	MT	Spruce	104	21	23.1	3	22	25	Fertilized 1971
3	OMT	Spruce	104	22	26.7	–	20	20	Fertilized 1969
4	MT	Spruce	114	23	25.6	8	20	28	Fertilized 1969
5	MT	Spruce	107	26	32.0	–	25	25	Fertilized 1974
6	CT	Pine	111	16	23.2	18	–	18	Uncut
7	OMT	Spruce	124	25	28.8	–	21	21	Fertilized 1965, 1966
8	MT	Spruce	94	24	29.1	7	16	23	Fertilized 1966, 1971
9	MT	Spruce	84	25	29.3	–	28	28	Cut 1964
10	VT	Pine	128	20	30.3	25	–	25	Uncut
11	MT	Spruce	103	29	34.1	–	26	26	Cut 1964
12	VT	Pine	71	21	27.6	20	–	20	Thinned 1959
13	MT	Pine	116	25	29.0	18	–	18	Thinned 1960, Fertilized 1968
14	MT	Spruce	92	21	24.5	5	15	20	Thinned 1960, Fertilized 1968
15	OMT	Spruce	121	25	26.1	–	23	23	Fertilized 1967
16	CT	Pine	80	17	21.9	21	–	21	Thinned 1959
17	OMT	Pine	113	30	35.5	12	9	21	Fertilized 1966
18	OMT	Spruce	125	32	32.0	5	20	25	Natural stand
19	OMT	Spruce	99	28	30.4	–	18	18	Fertilized 1967
Total						157	263	420	

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1981. Climatic variation in radial growth of Scots pine and Norway spruce and its importance in growth estimation. Seloste: Männyn ja kuusen sädekasvun ilmastollinen vaihtelu ja sen merkitys kasvun arvioinnissa. ACTA FORESTALIA FENNICA 171. 57 p. Helsinki.

Annual ring index series of Scots pine and Norway spruce for different localities and for southern Finland are presented. The climatic variation in periodic growth (5-year period) in southern Finland is about 11 % of the normal level. The results suggest that the data from 10 localities can be used in the computation of the index series for southern Finland and that the data from 10 relascope plots are required in the study of the climatic variation in tree growth in a given locality. The standard error of the estimate in actual growth estimation for past and future periods by the stand function method is about 23 %, the errors of the method involving increment boring being 6 % and 16 % respectively in past and future growth estimation. The respective methods yield about 20 % and 13 % of error in average growth estimation. With the aid of the average growth indices for southern Finland, in local growth estimation the accuracy in estimating actual growth for the future period by the method involving icrement boring is distinctly improved, the error being equal to 12 % only, while the accuracy in other cases is slightly improved.

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