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This pdf file contains the first 59 pages of the 372-page book, thus introducing the results of growth trend studies carried out in Finland in the beginning of 1990s.

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A new updating growth trend study will be carried out in Finland in 2007-2009. The results will be presented in the International Conference of Dendrochronology in Finland in 2010. For more details contact: kari.mielikainen(@)metla.fi or mauri.timonen(@)metla.fi
Growth Trends in European Forests
Studies from 12 Countries
with 127 Figures

European Forest Institute Research Report No. 5
Springer
Acknowledgement

This book is the result of a project initiated by the European Forest Institute (EFI).

The success of the project depended on the input and expertise of numerous scientists, who contributed to the project. We would like to thank all project participants for their efforts. In total, 63 scientists independently reviewed the individual contributions presented in this book. Their valuable comments and suggestions, which we thankfully acknowledge, helped to ensure the scientific standard.

We would also like to thank Ms. L航班 Robinson, EFI, for her assistance in administrating the project and her outstanding help to finalize this volume. We thank our publishers, Springer-Verlag Heidelberg, for the friendly and helpful cooperation in publishing this book.

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Foreword

The European Forest Institute (EFI) has five Research and Development priority areas: forest sustainability, forestry and possible climate change, structural changes in markets for forest products and services, policy analysis, and forest sector information services and research methodology. In the area of forest sustainability one most important activity has been the project "Growth trends of European forests", the results of which are presented in this book.

The project was started in August 1993 under the leadership of Prof. Dr. Heinrich Spiecker from the University of Freiburg, Germany, and it is one of the first EFI's research projects after its establishment in 1993. The main purpose of the project was to analyse whether site productivity has changed in European forests during the last decades. While several forest growth studies have been published at local, regional and national levels, this project has aimed at stimulating a joint effort in identifying and quantifying possible growth trends and their spatial and temporal extent at the European level.

Debate on forest decline and possible climate change, as well as considerations related to the long term supply of wood underline the importance of this project, both from environmental and industrial points of view. Knowledge on possible changes in growth trends is vital for the sustainable management of forest ecosystems.

From a methodological point of view, the leading idea in the project has been to utilise existing research plots and data from many countries to increase the empirical base and validity of the analysis. 44 scientists from 12 countries have contributed to this report. As such, the project is an excellent example of the basic idea behind EFI and its mode of operation: to create added value to existing data by pan-European research networking.

On behalf of EFI, I would like to express my warmest thanks to all those who have contributed to the project and to this report. In particular, I would like to thank Prof. Dr. Heinrich Spiecker for his outstanding leadership of the project, and the Editorial Board of this report: Prof. Kari Mielikainen from Finnish Forest Research Institute, Dr. J.P. Skovsgaard from the Danish Forest and Landscape Research Institute, Dr. Michael Kohl from the Swiss Federal Institute for Forest, Snow and Landscape Research, and Prof. Dr. Spiecker as the Chairman of the Editorial Board. I would also like to thank Ms. Ursula Gramm at Springer Verlag for her help in publishing this volume.

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Introduction

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Debates on forest decline and possible climatic changes emphasize the need for information regarding environmental changes and their effects on forests. In recent years, the condition of European forests has been systematically surveyed. For evaluation and interpretation of actual forest conditions long-term observations are needed. Only a few forest characteristics have been monitored over long periods of time. One of these characteristics is forest growth. For many decades, forest research institutions have installed permanent research plots and conducted tree ring and stem analyses to investigate long-term growth of forests. The aims of such research is to ensure sustainable forest production.

Recent investigations in European forests indicate both positive and negative changes in forest growth. In contrast to discussions about forest decline in the 1980s, several studies show that forest growth may have actually increased on specific sites (e.g. Abetz 1988; Kenk and Fischer 1988; Pretzsch 1992; Eilionsson and Juhannson 1993; Spiecker 1994; Becker et al. 1994; Holle 1995). A remarkable increase in growing stock of European forests has been reported (UN-ECE/FAO 1992; Kauppi et al. 1992; Kuusela 1994) which may have partly been caused by an increase in site productivity. Other possible causes for this observed increase are changes in tree species composition, age structures, silvicultural practices, spatial distribution of forest land and assessment methods.

Through these findings foresters were reminded that one could not simply rely on past growth observations to predict future growth. Even without human influence forests have always been exposed to environmental changes. As a result, growth rates have always been changing over time (Spiecker 1995). In addition, human activities are increasingly influencing the environment. Changes in litter raking, grazing, historical management (incl. regeneration methods, weed control, tending, thinning and their effects on genetic resources, species composition, age structures and forest structures), fertilization and liming, climate (including air chemistry), atmospheric deposition, occurrence of pests and diseases, disturbances caused by fire, storm and snow, as well as browsing have influenced site conditions considerably. The global increase of atmospheric CO₂ and atmospheric deposition of nitrogen have an impact on forests. The level of CO₂ is predicted to double within the next century (Houghton et al. 1990). In consequence, more changes in climatic conditions are expected.
Introduction

The above-mentioned environmental changes vary in space and time. Growth responses to these changes are modified by site and stand conditions. An impact of environmental changes on forest growth has to be assessed and therefore past growth observations may not reflect actual growth potential.

Growth reactions of trees are useful in identifying and quantifying possible environmental changes in their spatial and temporal extent while information about the effects of environmental changes may be used for the prediction of future forest development. In this context forest ecosystems could serve as bio-indicators. Furthermore, knowledge of forest growth trends is necessary for sustainable forest ecosystem management and for prognosis of wood supply. For these reasons the European Forest Institute initiated the project entitled "Growth Trends in European Forests - Has Site Productivity Changed?". In a planning meeting in 1993 the project's concept was developed. In 1994 a workshop was held in Joensuu/Finland, during which the scientific approach was discussed. The research was given a frame of objectives, data and methods to facilitate the comparison of results on a European scale. This frame was published as the EFI Working Paper No. 4 "Growth Trends of European Forests - Has Site Productivity Changed?" (Spiecker et al. 1994). Preliminary results of the project were presented at the IFI&F World Congress in Tianjin, China in 1995 (Reisenede et al. 1995, Spiecker et al. 1996). Finally, a research network was developed to evaluate growth data on a European level. The results of the joint effort of the participants are presented in this book.

While individual reports on growth and yields of forests have been published on local, regional and national levels, this project aimed at stimulating a joint effort in aggregating existing growth information and in identifying and quantifying possible growth trends and their spatial and temporal extent on a European level. The main objective of the project was to provide a retrospective view of the growth of European forests over the last decades. In most cases, data originally sampled for other purposes were used. This was possible because a large amount of information on forest growth has been accumulated in forest research institutions.

Growth of forests is modified by various natural and human influences. The main interest in growth trends in this project relates to changes in site productivity, which may have been caused by land use history, climate changes or atmospheric deposition.

The terms "site", "forest site productivity" and "growth trend" have been defined in the context of this project as follows (EFI Working Paper No. 4):

• Site

The term site is used to describe the sum of environmental conditions (climatic, edaphic, topographic and climatic conditions, including atmospheric composition) of a site at a particular location.

• Forest Site Productivity

Forest site productivity is defined as the woody biomass production potential of a site. In this project the term site productivity is limited to the wood production potential of a site for a particular tree species, provenance or forest type. For example, growth of volume, basal area or height may serve as an indicator of site productivity.

• Growth Trend

A trend is a long-term change of a mean level. Growth trends within this project are indicated by long-term site-related deviations from expected growth. This project particularly focuses on the detection of trends during recent decades. For interpretation of growth trends 50-year-periods, preferably even longer periods, should be investigated.

It is difficult to separate growth trends which reflect long-term changes in site productivity from episodic changes caused by extreme events such as frost, drought, snow and storm damage, fire, insect or fungal diseases or by a combination of several events, which are often followed by a reverse change. Changing weather conditions typically cause short- and medium-term growth variation. However, effects of extreme climatic events on growth may have an impact on growth for up to several decades. Such an event may have an effect on the foliage, the root system and the water transportation system within a tree. In addition, it may change tree competition as trees grow under varying gain growing space and resources from their weakened neighbors. These potential changes to stand dynamics initiate long lasting changes of individual tree and stand growth.

Quality data and evaluation methods are of central importance for reliable growth trend analysis (Sterba, in this volume). Three data sources were included in the project: research plot data, inventory data and tree ring or stem analysis data. Each of these three data sources has its own advantages and limitations. Stand history and site conditions on long-term permanent plots are generally well-known. Tree competition over time can be determined when the locations of individual trees are mapped. Volume growth per ha can also be derived from permanent plot data. However, permanent plots are not usually representative of larger areas because they have been established for other purposes and they may lack replication (Köle et al. 1995). Trees on permanent plots are remeasured at intervals of several years. The time of consecutive measurements has an effect on identification and description of short- and medium-term growth changes. Therefore, references to changes in relation to the findings of periodic measurement should be interpreted cautiously.

Forest inventory data, on the other hand, are usually sampled on a consistent statistical basis and are, therefore, representative for the entire inventory area (Köle, in this volume). Even so, they lack detailed information on stand history, management and site conditions. Stem analysis, as the third source of data, allows the reconstruction of diameter and height growth over long time periods with annual resolution. However, it is not possible to find individual trees which represent site productivity over a long time period (Spiecker 1992) because stand density and aging have an effect on individual tree growth. The density effect is less pronounced for dominant trees although their growth is affected by neighboring trees as long as the trees have not grown free of any competition. Tree-ring data are appropriate for detecting agents with short- and medium-term influence on tree growth. Analysis of height-in
Increment is preferable in long-term observations since height growth is less influenced by the effects of competition. In such cases reliability of height growth as an indicator of site productivity has to be evaluated by long-term permanent plot data which provide information about volume increment per ha. A combination of different data types and variables may finally provide the best results. Combining single tree data with plot data helps to overcome some limitations of single tree growth data.

In some countries no long-term growth data were available in a form appropriate for analyzing possible growth trends. Furthermore, the time span of existing data varied from a few decades to several centuries. Some data reported in this book referred to case studies on rather small areas. Others, for example some inventory data, to larger regions or nations. Besides original studies, some summarizing papers are included in the book. Since the data analyzed were usually not collected for analysis of long-term growth trends, a variation in the applied methods was unavoidable. Some data sets could not be used for the comparative analysis, for example permanent plot data from stands that were considerably damaged by storm, snow, insects, fungi or fire. Likewise, fertilized plots could not be included in the trend analysis either. Information on stand structure and stand history was not always available in full detail. In some cases only data for rather short periods were at hand. In Southern Europe, for instance, trees are generally managed in short rotation periods and data from previous generations were at hand only in rare cases. Other data, such as inventory data, can be obtained for many decades as, for example, Finland and Sweden. In contrast, the first sample based inventory on forest district level in Switzerland was conducted in the early 1970s. In Germany the first nation wide inventory was conducted in the mid 1980s.

Data were checked, evaluated and interpreted by each author individually according to the recommendations of the EFI Working Paper No. 4. Due to the different data sources available different methods had to be used. Because of these shortcomings the book does not present growth development of forests in Europe in a uniform and statistically representative way. However, the results facilitate conclusions at the European level.

To determine possible growth trends, a growth reference describing expected growth is needed. Growth references have to be based on past experience. Preferably, growth data from earlier growth periods are used. In some cases yield tables and other growth models are used as references. A reference is valid only when it represents the site and stand conditions as well as the management regime of the investigated forest in the reference period. By using yield tables or other growth models as growth references, the following problems have to be considered:

a) How do management practices (regeneration methods, tending of young stands, thinning regime etc.) of the reference stands influence reference values?
b) How do fluctuations in the growth conditions influence reference values?

For example, unseasonable weather conditions lasting several years during the observation period may have an effect on the growth model used as a reference.

References may be biased due to an uneven distribution of site types in different age classes. If, for example, the oldest stands used in yield tables are grown on relatively poor sites, a comparison using these tables as a reference may lead to bias in estimation of actual productivity.

Twenty-two papers written by 43 scientists from 12 countries are presented in this book. Most studies were conducted in Northern and Central Europe, only two studies refer to Southern Europe.

Fig. 1. Map showing the borders of the studies.

By analyzing the spatial and temporal patterns of growth trends some hints regarding possible causes were expected. The results of the individual studies are discussed and summarized at the end of this book. Consequences for decision-makers and researchers in the field of forest growth and other fields are described.
Abstract

Precisely dated subfossil trees and long chronologies of tree growth provide a unique calendrical record for studies on growth variations in the past and climate history. A total of 1465 subfossil Scots pines (Pinus sylvestris L.) has been sampled from 42 sites in northern Fennoscandia. The sampling sites are mostly small lakes in the timberline zone located between 68°30' N and 70°00' N and at elevations ranging from 75 m a.s.l. to 515 m a.s.l. A total of 1023 subfossil trees have been dated by dendrochronology. From the dated trees we have constructed a chronology for each growing site and also a common chronology for the entire area. In this study, subfossil pines are used as "growth reference" of forest site productivity in the past. The abundance of subfossil pines makes it possible to explore the long-term stand history of pine at each site over thousands of years. The unbroken tree-ring record extends from the present back until 165 B.C. and after a 150-200-year gap until about 7500 years before the present time. The continuous part of the master curve is 664 years longer than the earlier published pine chronology for northern Sweden. This 7500-year pine master chronology can be used for dating subfossil pines from a wide area in northern Fennoscandia.

The subfossil pine material has been used for studies on the Holocene climatic history, growth variations, year-to-year variability in ring widths, periods of germination and mortality, population size and age structure at the sampling sites and tree-line changes. These combined data are valid indicators of diverse environmental changes in the past. A detailed register of the growth variations is available for two periods in mid- to late-Holocene times. The data for the period 4500-3000 B.C. suggest increased variability in tree growth after 3800 B.C. The mid-Holocene climatic change at this time was thus largely the result of a shift towards less stable
Construction of a 7500-Year Tree-Ring Record for Scots Pine

The dating accuracy of variations in tree growth and climate is 1 year. The mean annual growth has temporarily varied significantly, being highly dependent on growing conditions at each site, but when the entire material is considered, in the long term the mean ring width has remained rather constant, being approximately 0.6 mm. The available data from the Holocene climatic optimum and late Holocene do not differ from each other in this respect.

1. Introduction

Precisely dated subfossil trees and long chronologies of tree growth can significantly increase the knowledge of growth variations in the past and climate history. The abundance of subfossil pines makes it possible to explore the long-term stand history of a million years. The comparison of data from several sites will identify common changes in tree growth, which represents important evidence of large, regionally representative past climate-based growth changes. For the interpretation of growth trends in the past few decades, also long-term changes should be investigated as background information.

Pine (Pinus sylvestris L.) spread over northern Fennoscandia by 8000-7500 B.P. (conventional radiocarbon years). Sites well beyond the limits of present distribution of pine were populated under favourable climatic conditions in 7000-5000 B.P. The maximum spread of pine occurred between 6000 to 4000 B.P. and was followed by a retreat during the succeeding millennia (Hyvarinen 1975, 1976, Eronen 1979, Eronen and Huttunen 1987, 1993). Pine is a relatively long-living tree species and the ring-width variability is clear, making reliable dendrochronological dating possible. The structure of subfossil wood several thousands of years old is sufficiently well preserved to allow the detection of cell walls and boundaries of tree rings for measuring.

In areas where trees grow in marginal environments, the control of annual growth by environmental factors, particularly climate, is strong and clearly discernible (Fritts 1976). In the coniferous forest limit in northern Fennoscandia, the variations in tree-ring widths are very similar within wide areas. This makes the correlation of tree rings over large areas possible, and allows covering of short gaps in the site record with data from another growing site. Regional differences between sites indicate local differences in growing conditions.

The subfossil pine material has been used for studies on the Holocene climatic history, growth variations, year-to-year variability in ring widths, periods of germination and mortality, population sizes and age structures at the sampling sites (Zetterberg et al. 1994) and tree-line changes (Eronen and Zetterberg, in press). These combined data are valid indicators of diverse environmental changes in the past.

2. Material and Methods

A total of 1465 subfossil Scots pines (Pinus sylvestris L.) has been sampled from 42 sites in northern Fennoscandia. The sampling sites are mostly small lakes in the timberline zone located between 68°30' N and 70°30' N and at elevations ranging from 75 m a.s.l. to 515 m a.s.l. (Fig. 1). Individual lakes normally yielded several tens of subfossil logs. Over 100 pine trunks were collected from five small lakes, the record being a lake where a total of 219 subfossil pine trees were sampled. Best sites for the preservation of subfossil trees are small ponds with a thick layer of mud on the bottom. The majority of the trees are buried in the bottom sediments. The trunks, totally embedded in the soft sediment, can be located by the help of divers. The longest trunks reach a length of 15 m and the maximum diameter is more than 50 cm. Most of the sampled trees are well preserved, so that nearly all tree rings of the cut discs could be measured. Dead decayed trunks, stumps with only the base of the trunk preserved, and young trees containing below 50 annual rings were rejected as unsuitable for dendrochronological studies. Sample discs were cut by chainsaw.
1. Construction of a 7500-Year Tree-Ring Record for Scots Pine

About 1–1.5 m above the original root plate and higher up from the trunk when the lower part of tree was not preserved. The sampling methods are described in detail in Zetterberg et al. (1994).

The discs were dried at room temperature in the laboratory and the upper surface polished for ring-width measurement. Measurements were made with microscope along two to four radii and the mean value of these measurements was used to produce the tree-ring curves for individual trees. The replication facilitates the identification of partially absent rings and averaging the data across radii reduces the "within-tree" noise. The establishment of the chronologies requires the linking of tree-ring records together by means of the cross-dating. The cross-dating was first done by statistical correlation between series and it was always confirmed by visual inspection of the ring-width graphs. The most common reason for failure in dating was the occurrence of compression wood in trees which had grown at the shore and tilted towards the lake during their lifetime. Tree rings grow wider and more dense on the tilting side of the trunk in order to compensate for the lean and in an attempt to right the trunk. Difficulties also arose when the number of annual rings in a tree was less than 60.

3. Dendrochronological Dating and Development of the Long Tree Ring Record

A total of 1023 subfossil trees have been dated by dendrochronology in this study.

The age distribution of the dated samples is given in Fig. 2. In this figure the material has been divided into three parts based on the origin of the samples: Enontekiö, Utsjoki and Inari areas. Enontekiö lies in the westernmost part of our study area, while Utsjoki is in the northernmost and Inari in the easternmost part.

The continuous tree-ring curve based on the dendrochronological dating extends back more than 2000 years, to the year 165 B.C. (Zetterberg et al. 1994). Over 200 subfossil trees from several sites in northernmost Finland are bound to the absolute chronology, and sample replication is more than 20 trees in most parts of the time period. Thus, the northern Finland absolute chronology can be regarded as a master curve and as such it is the longest for northern Europe so far.

Most of the dendrochronologically dated trees (approx. 800 samples) belong to the older part of the long master chronology, which is fixed to the time scale by many radiocarbon dates made from samples of subfossil wood. This continuous, more than 5000-year-long part of the master chronology now extends approximately to the year 7500 B.C. The 150-200-year-long gap, separating the older part from the younger absolute chronology, can probably be bridged in the near future. The age of the older chronology is known within the error limits of the radiocarbon method (several decades), but inside the master chronology the accuracy of the tree-ring series is 1 year. Thus, it can be used in studies of long- and short-term growth variations in northern Fennoscandia.

Together with the subfossil trees, we also collected tree-ring samples from a large number of living forest-limit pines, which have been used for construction of the youngest part of the Finnish Lapland master chronology. Tree-ring measurements from beams of old houses in northern Lapland (Zetterberg 1990) were also of great importance in cross-matching the curves derived from living and subfossil trees.
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4. Growth Trends and Cycles, Examples from Utsjoki, Northern Finland

We used the long tree-ring records to study the growth trends (i.e. long-term change of a mean level) at several growing sites in northern Fennoscandia. One of the sites is Lake Ailigas in the Teno (Tana) River valley, near the main village of the Utsjoki commune (69°54'N, 27°04'E, 75 m a.s.l.). When developing the chronology for the Lake Ailigas, we did not employ any "standardization" (i.e. correction to remove the age-related trends in individual series) in the chronology construction in order to maintain all possible long-timescale variations (e.g. see Cook and Briffa 1990; Cook et al. 1995). Thus, the data contain some sample-age-related bias in different periods. The site chronology constructed from raw ring-width data of 78 subfossil pines is shown in Fig. 3. The general curve from 100 B.C. to A.D. 1250 is mostly based on several tree-ring series. Sample depth is above one tree for half of the time and from five to nine trees during the remainder. Between the late 800s and the 930s the curve is based on only two to four trees. The data are also scarce from 1250 to the early 1400s. In the following, we will summarize the interpretations on growth trends and climate changes made from Lake Ailigas subfossil pines given in detail in Zetterberg et al. (1994).

All pines living between 130 and 120 B.C. indicate very poor growth followed by warming and pronounced radial growth after 120 B.C. In the beginning of the first millennium B.C. tree rings were relatively wide, while in the latter part of the century the growth decreased. More favourable conditions prevailed again around the beginning of the Christian era and in the first century the growth reached peak values around 60 A.D. Reduced growth occurred between A.D. 8 and 22 and again in A.D. 40. Fluctuating tree growth in relatively favourable conditions prevailed during the second century. This clearly favourable growth period was interrupted by years of poor growth, first in 111 - 114 and again 150, 168 and 187. During the third century, radial growth decreased, and the fourth century was even less favourable for the growth of pine. The fifth and sixth centuries are characterized by significant growth variations, among which the decline in growth in the year 536 A.D. was extremely abrupt. The strong variations in tree growth then subsided during the seventh century. The eighth century was characterized by relatively wide rings, while growth improved again in the late eighth century. There were no strong growth variations in the 10th century and in the early 11th century. From 1044-1060 A.D. growth was exceptionally poor, but after the cool phase, growth rose for three decades. The oscillations in tree growth had started in the late 10th century and continued during the first half of the 12th century. Early 13th century summers were mostly cool, but later tree growth increased to a maximum in 1227. The tree-ring curve showing decreased growth, albeit based on few data, indicates that the period from 1260 to 1320 was characterized by anticyclonic conditions. After 1330, the curve demonstrates a large increase in tree growth. For this period the curve is based only on two trees, but the same trend can be seen in other data from Utsjoki (Fig. 3). This additional tree-ring data was needed to connect the Lake Ailigas chronology to the present time. The other curve is based on two-ring samples taken from living pines and old wooden buildings in Utsjoki (Zetterberg 1990) and subfossils from other small lakes in the Tana river valley. The previously published tree-ring curve from northern Sweden (Tornetrask) also shows a short but distinct peak in the beginning of the 14th century (Briffa et al. 1992). In these data, the peak was followed by a decrease and then average growth during the rest of the century. Our new data from the Inari area (Zetterberg, unpublished) also shows a clear rise in growth after 1320. The growth peaked during 1350 and was followed by a decrease. The distinct growth peak in the Utsjoki regional growth curve after the 1450s is also obvious in the data from Inari. The distinct growth peak in the Utsjoki regional growth curve after the 1450s is also obvious in the data from Inari. The 16th century was a period of increased growth and was followed by a distinct decrease after 1600. The 17th century was mainly a period of very low growth. After the 17th century, the mean growth curve from Utsjoki shows strong fluctuations with low mean growth during the end of the 18th century, 1840s and in the beginning of the...
20th century. Periods of increased growth occurred during the 1750s, the 1830s, in the latter part of the 19th century and in the 1920s. From the tree-ring data collected from different parts of Utsjoki commune, we produced a cubic smoothing spline standardized chronology (Fig. 4, A). The chronology is based on 100 subfossil trunks (including 78 trees from Lake Ailigas), 10 historical beams from buildings and 20 living pines. The growth trends of the Lake Ailigas one-site original chronology listed above, are much less obvious in the standardized curve, but this curve is more suitable for dendroclimatic reconstructions. A spectral analysis was carried out to check preliminarily if there are any strong periodicities in the Utsjoki tree-ring material. The relationships of index values of the chronology are shown as different points in time (Fig. 4, B). The periodogram presents the chronology in terms of cycles of different lengths that generate the time series. The variations are described in terms of cycles of sinus and cosinus. The highest frequency has half as many cycles as the number of tree-rings. A smoothing transformation for the periodogram was obtained by a Tukey-Hamming smoothing procedure with a 15-year span.

4. Discussion and Conclusions

The subfossil pine material from northern Lapland has been used for studies on the Holocene climatic history, growth variations, year-to-year variability in ring-widths, periods of germination and mortality, population size, and age structure in the sampling sites and tree-line changes. The combined data have given diverse indications of environmental changes and changes in the site productivity in the past. Detailed tree-ring studies of the growth variations in northern Fennoscandia is already available for two periods in mid- to late-Holocene times. The data for the period 4500-3000 B.C. suggest increased variability in tree growth after 3800 B.C. The mid-Holocene climatic change at this time was thus largely the result of a shift towards less stable growing conditions (Zetterberg et al. in press). For the late Holocene period from 100 B.C. to the present, growth and climate variations have been studied to the accuracy of 1 year (Zetterberg et al. 1994). The mean annual growth temporarily varied significantly, being highly dependent on growing conditions at each site, but when the entire material is considered, the mean ring width remained rather constant in the long term, being approx. 0.8 mm. The mean ring width for the Holocene climatic optimum (0.55 mm, Zetterberg et al. in press) and the late Holocene do not differ from each other in this respect.

In our procedure we used tree-ring chronologies based on raw unstandardized data in order to maintain all possible long-timescale variations. The traditional approach to the palaeoclimatological interpretation of old trees is to develop long series of averaged ring-widths or standardized ring indices and to reconstruct palaeotemperatures using regression equations calibrated against modern instrumental records (e.g. Fritts 1976). In northern Fennoscandia the growth of tree-limit pines is strongly correlated with summer temperatures (Hustich 1948, Mikola 1950). This situation has permitted the reconstruction of past summer temperature variations (Aniol and Eckstein 1984; Briffa et al. 1988, 1990, 1992). These interpretations are based on the principle of uniformitarianism; i.e. on the assumption that the environmental/climatic signal represented in the tree-ring time series has not changed over...
time. Apart from the climate, other factors such as site conditions, plant diseases, flowering and seed maturation, fire etc. influence tree growth. Detailed descriptions of representative sites are necessary to allow us to distinguish between local tree growth variations and large scale variations which are mainly caused by climatic changes in the forest-time zone. 

The periodicity of pine growth in northern Fennoscandia has been studied by Siren and Hari (1971) and Briffa and Schweingruber (1992) for example, who both found periodicities of different length in the tree-ring data. Periodicity is obvious also in our data (Fig. 4, B); especially between 2 and 50 years, there are several peaks. On the other hand, periods of 2 - 5 years show only weak powers. However, there remains a number of uncertainties in the data. Several frequencies tend to occur together; in addition, there is a considerable amount of random noise evident in the time series. An areal chronology may also reveal purely local cycles. This random periodicity may be detected and possibly eliminated when several areal methodologies are compared. Special analysis may be applied to pairs of areal chronologies to examine their covariation at each period or reciprocally at each frequency. 

Climatic stress, such as extremely cold conditions, influences the number of dying trees. Above-average warm springs can increase the number starting their growth. Therefore, during periods of high inter-annual temperature variability (e.g. some rather climatic factors), a greater numbers of trees are likely to die and others germinate than would be the case under more stable conditions (cf. Kullman 1993, Kallina 1995). The variations in germination and dying-off of trees can be used as a complementary source of information on pine growing conditions (Zetterberg et al. in press). The size of the pine population at a sampling site is also indicative of past growing conditions and site productivity. In marginal environments, such as the subarctic tree line, the tree population usually grows larger during favorable, relatively warm periods than during unstable or cold periods. 

It was shown that in the Lake Ailigas data there were only four main regeneration periods between 300 B.C. and 1370 A.D. (Zetterberg et al. 1994). The quantity of pine generations over almost 3000 years indicates that conditions were seldom favorable for flowering and maturation of pine seeds. It is known from modern forestry studies that the regeneration of pine in the forest-limit zone requires at least two consecutive summers warmer than the "average" of these occurred, at present, probably only a few times in a century (Siren 1981). The Lake Ailigas subfossil pine show that conditions were similarly harsh for the northern pines in the past. 

Subfossil logs have been found over a tens of kilometers beyond the present limits of pine. Pine distribution has been widespread over large parts of Northern Fennoscandia during the last 8000 years. In pine forest and at altitudes above the highest present occurrences of pine trees, indicating more favorable conditions thousands of years ago. Briffa (1979) surveyed earlier studies on the distribution of subfossil pines in Finnish Lapland. These, together with pollen studies, show that the maximum extension of pine in Finnish Lapland occurred during the mid-Holocene time (Eronen and Huttunen 1987, 1993). The dendrochronological dating and development of the 7500-year tree-ring record resulted in a large number of new data of pine subfossils. The 1023 subfossil trees dated in this study have multiplied the number of dated subfossil trees in the area.

The new dated trees confirm the earlier conclusion that the pine forests reached their maximum extent in northern Fennoscandia 6000 - 2500 B.C., (6000 - 4000 B.P.). The subsequent retreat shows somewhat different patterns in different regions, but the general trend is a gradual dying-off and receding from the summer growing sites (Eronen and Zetterberg in press). 

The future aims of this research are: 1) bridging the short gap in the tree-ring data before the Christian Era and lengthening the existing chronology to cover 8000 years, 2) developing several continuous site chronologies as long as possible in order to study changes in the forest site productivity, 3) detailed study of the growth variations and their climatic interpretations for the entire regional chronology. The 7500 year pine master chronology is suitable for dating of subfossil pines and archeological pine wood from a wide area in northern Fennoscandia even though it is not yet fully complete. 

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References 


Growth Trends of Forests in Finland and North-Western Russia

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Abstract

Several studies concerning growth trends in Finland and north-western Russia are cited in this paper. Many of these studies are from the northern part of the area, close to the Arctic timber line. The forests in that region are especially sensitive to small changes in the environmental conditions and thus are an excellent source of information on recent climatic changes.

In the North, both negative and positive trends have been found. Local forest growth decline of unusual extent was observed around non-ferrous smelters in the Kola Peninsula, north-western Russia. In addition to the total dieback of forests near the smelters, reduced growth of Scots pine was detected up to 30-35 kilometres away from the sources of pollution.

The area of local forest decline covers only a small fraction of the total forest area around pollution sources. In the major part of forests in Lapland, the radial increment of Scots pine has been at a clearly higher level than in the 19th century. This is mainly due to more favourable climatic conditions in this century, especially in the 1930s. This conclusion is supported by studies conducted in other parts of Finland. The nitrogen deposition, many times higher than in the North, has caused no measurable trends in the radial increment of Scots pine in southern Finland.

In the region of St. Petersburg in Russia, ageing study stands show no decrease in current annual volume increment during the last few decades. This abnormal behaviour of mature stands can be a sign of increased nitrogen deposition (25 kg ha⁻¹ annually) or of normal long-term climatic variation.

1 Introduction

A key question in the discussion on forest decline in northern latitudes of Finland and Russia has been the doubt about the sensitivity of trees to decline due to stress.
caused by climate, gaseous pollutants and soils with low buffering capacity against acid deposition. The effects of pollutants, coming from the North (Kola peninsula) or from the South (Central Europe) have been widely discussed during the last 10 years. The existence and direction of these effects has, however, remained unclear.

The national forest inventories (eight NFIs since 1923) conducted in Finland show an increase of more than 60% in forest volume growth from 1950 to 1990 (Tomppo and Siitonen 1991). The main reasons for this increase are supposed to be changes in silvicultural practices and stand structure. Among these practices, the drainage of peatlands, regeneration of low-productive stands, forest fertilisation and the change from selection felling to clear felling are the main causes behind the growth increase. Deposition of man-made pollutants, originating mainly from the burning of fossil fuels and agriculture, cannot, however, be excluded from the list of possible causes for increasing productivity of forests.

Fire has always played a decisive role in boreal forests. On the one hand, it has improved soil productivity by releasing nutrients from the thick humus layer, typical of old spruce-dominated stands. On the other hand, fire has in the past caused disturbances in individual tree growth, which is difficult to detect and analyse.

In the northern latitudes of Fennoscandia, the variation in tree growth between years and decades can be very high, thanks to the harsh climate and long-lasting lag effects (Siren 1961). This variation makes the detection of possible growth trends difficult.

2. Trends Showing Decreasing Growth

There are few publications showing clear decreasing trends in tree growth. Nöjd and Reams (1995) have published results on the basis of data measured around the big nickel smelters in the Russian Kola Peninsula, north of the Polar Circle, and along a gradient line transversing into Finnish Lapland. The annual deposition in 1990 of sulphur dioxide ($SO_2$) has been 230 kT from Monchegorsk and 190 kT from Nikel. The depositions of nickel and copper originating from Monchegorsk are 2-3 kT. There is a circle of 5 km in radius of dead forest around the Monchegorsk smelter. Growth decline can be detected up to 30-40 km from the smelter. The variation in pine growth (annual rings) is presented in Fig. 1 as a function of time and distance from the pollution source. The growth decline began at the end of the 1940s and the area is constantly expanding. The distance from Monchegorsk to the border of Finland is more than 100 km.

The total emission of sulphur in Finland is less than half of that emitted by the two above-mentioned smelters. The emissions have diminished by 80% since the beginning of the 1970s. Thus the growth decline caused by sulphur cannot be detected in Finland.

3. Trends Showing Increasing Growth

3.1. Inventory Material and Permanent Experiments

Nöjd et al. (1994) have analysed data from three national forest inventories (1950-1990) by modelling stand growth as a function of stand age and volume. Comparing the model results with actual field measurements in successive inventories showed that pine stands in the 1970s grew better than in earlier times. This increase could not be directly explained by climate variables. The trend disappeared partly or totally when the growth values were adjusted by existing annual ring indices.
Henttonen (1990) found a positive trend in the width of annual rings of Norway spruce in southern Finland between 1967 and 1987. This short-term trend could be explained by increasing temperature and precipitation during that period. Since 1987, successive dry summers, followed by abundant seed years, have caused the positive trend to end.

Sennov (1995) has studied the culmination of annual volume growth in stands dominated by pine, spruce or birch. Long-term experiments, established in the 1930s, did not show a clear culmination point at the age of 40 to 50 years as was supposed to happen (Fig. 2). On the contrary, some of these 9 study plots showed a constant or increasing growth in the 1970s and 1980s at a relatively high age. The author suggests that this increase in stand increment may be a sign of the beginning of climate change. The annual nitrogen deposition, about 25 kg ha\(^{-1}\) in that region, can have caused the trend. The short duration of the trend and the lack of climatic data in the analysis make the conclusions still uncertain. The trend can at least partially be caused by natural climatic variation or stand dynamics of mixed stands.

### 3.2. Annual Ring Analyses

Hari et al. (1984) searched for a trend using annual ring data, measured in strict nature reserves in southern Finland. The material consisted of old stands (established between 1680 and 1800) for reference and younger stands (established between 1800 and 1900) for studying the trend. The existence of the trend was tested by comparing the growth of the young trees with the age trend curve estimated using the old trees. The total number of sample trees was about 400.

The results suggested that since the 1940s the annual rings of pine have become increasingly wider than the reference curve suggests. The authors concluded that this was probably caused by an increase in the concentration of atmospheric CO\(_2\).

Based on annual rings of 98 old Scots pines (ages 300 to 400 years) close to the northern cutover line in Finnish Lapland, Hari and Arovaara (1988) studied the trend in conditions where the depositions of sulphur and nitrogen were at minimum levels. The method used was to develop a climatic growth model for Scots pine by using the measured climate data from 1906 to 1940 as predictor variables. This model was then used to estimate the width of the annual rings between 1940 and 1983 (Fig. 3).

The results showed that the actual width of annual rings has been higher than the model estimate during the last few decades. This trend was also found by Alekseev (1995) in the Russian Kola Peninsula. The uncertainty lies in the fact that the period 1906-1940 was climatically highly unusual in the whole of Lapland. After the severe frost damage of 1902, large numbers of pines died. Those that survived took as much as 20 years to recover.

The authors caution that the model is sensitive to slight changes in selecting a parameter describing the autocorrelation in the ring width series. Recovery from exceptional damage may also have affected the model parameters and estimates.
4. No Trend

On the basis of annual rings from old, unmanaged stands, Sinkevich (1995) studied the growth variation of Scots pine in Russian Karelia. He modelled the long-term cyclic increment fluctuation using the polyharmonic model. Data on solar activity, average temperature of the growing season and precipitation during July were also used in the model. The model was also used for making prognosis about future growth variation.

The results suggested that there is a high cyclic fluctuation in the radial increment of Scots pine. This fluctuation makes it impossible to find trendlike changes caused by the greenhouse effect in this data.

Eronen and Zetterberg (1992) have constructed an annual ring calendar of almost 8000 years using subfossil trunks, found from lakes close to the northern timber line in Lapland. Their results show that 4000–6000 years ago the climate was more favourable for tree growth than today. This variation in radial growth has been greater during the last 3000 years than before. Variation or trends, different from those in former times, cannot be detected this century (Fig. 4).

Mielikäinen and Timonen (1995) have studied the variation in the radial increment of Scots pine in southern Finland. Their first data set consists of increment cores, gathered from old, untouched forests in strict nature reserves. This set of data suggests no decline or increase in the radial increment of different age classes during the 20th century. This result is supported by increment cores taken from permanent experiments. The residual variation around the individual tree growth model developed was independent of the calendar year.

The height development of dominant trees differed from the site index curves published by Gustavsen (1980). This difference can mainly be attributed to differences in stand history between the two sets of data. Old stands in the Gustavsen’s data may have been affected by selective felling some 50 years ago.

5. Discussion and Conclusions

Different, and partly contradicting, growth trends have been reported for Finland and north-western Russia. This may be caused by differences in the data used. The often unknown stand history (wind, fire, management) makes conclusions uncertain. The recovery of trees after human or natural disturbances may have been interpreted as a trend caused by climate change. Thus all growth variation should be compared to the variation in climate. Another problem in interpreting the results is the different time scales of the studies. A scale of a couple of decades must include trends which in a longer time span would turn out to be the result of natural growth variation.
One conclusion is that there is no clear growth trend visible in most parts of Finland and north-western Russia attributable to air pollution or changing climate. A possibly positive trend was found only in the region of Saint Petersburg. The causes for our conclusion are:

1. The annual deposition of nitrogen, about 5 kg ha\(^{-1}\) in Central Finland (and much less in northern parts of Russia and Finland) during the past 20 years, is unlikely to cause abnormally high growth to be distinguished from long-term growth variation. The corresponding deposition, 25 kg ha\(^{-1}\) in the region of Saint Petersburg, may have caused an increase in stand volume growth during the latest few decades.

2. The temperature and precipitation in the growing season do not show an increase in the last 60 years. On the contrary, the summers from 1961 to 1990 were cooler than in the preceding decades.

3. The long-term cyclic variation in tree growth is so pronounced that it can conceal the beginning of abnormal trends.

4. It is very likely that the increase in the total production of Finland's forests during the last 40 years can be explained by changes in silvicultural practices.

References


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Short- and Long-Term Natural Trends of Scots Pine (*Pinus sylvestris, L.*) Radial Growth in North- and Mid-Taiga Forests in Karelia

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Abstract

Tree-ring data of Scots pine were collected in north-western Russia, in the Republic of Karelia, between the 62nd and 65th latitudes. Due to the remote location and favourable position in regard to prevailing winds, the region is considered relatively free of airborne pollution.

The analysis of the dynamics of radial growth was based on separating of quasi-periodic components and approximating by a polyharmonic model. Forecasting increment dynamics was done by summing up the reliable harmonic constituents for a defined span of time.

In the north taiga, the occurrence of about 18- and 25-year periods is approximately equal. In the eastern mid-taiga subzone, the spectrum expansion shows a decrease in frequency corresponding roughly to a 22-year period. A temporal shift of approximately 30 years between stands in the north- and mid-taiga was observed. A 50-year fluctuation was also evident which coincided with noticeable increment decrease. The most noticeable increment decrease occurs when low- and middle-frequency cycle components simultaneously reach the minimum. In the present century, a deep increment minimum took place around the year 1960 in the north taiga, and around the year 1990 in the mid taiga. The lowest levels of increment variability in the mid-taiga subzone are close to the characteristic levels of variation in the north taiga.

1. Introduction

In the search for evidence of cycles in tree-ring series, the most frequently emerging observations include the so-called quasibiennial-oscillation, cycles around 3 or 4 years, and 5 to 7 years. In addition, in the literature, there is generally some support for the 11-year (sunspot) cycle, and, more importantly, substantial evidence for the 20-year cycle. According to Burroughs (1994), the evidence does not distin...
Short- and Long-Term Natural Trends of Scots Pine cycle. There exists also strong support for 80- to 90-year and 180- to 200-year cycles. In the present work, fluctuation of periods between 40-60 years and about 100 years were found most promising for extrapolation. Forecasting the radial dynamics is based on the assumption that if a simple periodic process has taken place in the course of several complete cycles, then it may last for at least the next whole cycle. Apart from this, the link between biological phenomena and periodic processes in planetary movements in space lasting thousands of years and during almost unchanged, support the idea. After verifying reliable harmonic coefficients, the forecasting of increment dynamics is done by outlining them up every defined span of time. Naturally, the longer the series of available observations, the more reliable is the computation by polynomial model. The periodic changes in total increment variation are very complex even in undisturbed forest sites. Consequently, at present no unambiguous conclusions can be made about amelioration or deterioration of forest productivity. The statistical confidence of the amplitude of separated sinusoids is evaluated in this work by minimum square errors of the approximations. In addition to statistical confidence, a plausible physical explanation is needed, a biological sense of each component and consideration of its occurrence in other natural processes.

2. Material

The pine stands where tree-ring material was collected are located between 62° and 65° N in the Republic of Karelia, in north-western Russia. Samples were collected in two main areas, the Kostomuksha Nature Reserve in the north-taiga subzone, and the Vodlozero National Park in the mid-taiga subzone. Due to the remote location and favourable position in regard to prevailing winds, the aerotechnogenic discharges from Western European cities have not been detected in the region.

The investigation covered 100-300-year-old, even- and uneven-aged stands, located on the upland plain. No signs of tree-felling or other kinds of human activities were evident in the sites. The soils are sandy podzols on glacial deposits of varved clay. Average height of trees was 22 m, and the volume of the growing stock between 150 and 300 m$^3$. The mean-value functions (Cook et al. 1990, Schweingruber 1993). The mean index series, also called site chronologies, were produced by combining individual trees within each stand. The index series were generalised within the uniform conditions of the site and climate. When generalising for each calendar year, all the trees were checked, and the data were excluded which fell beyond the range of normal distribution at a 10% confidence level. When the current-year indices differed greatly from the normal distribution, the maximum mode was taken as a mean value. The 7 to 25 cross-sections from each of the 18 stands, enabled the construction of five generalised mean-value functions. Two master chronologies for the main research areas are presented in Fig. 1. The Kostomuksha Nature Reserve represents the north-taiga subzone, and the Vodlozero National Park represents the mid-taiga subzone.

Analysis of the dynamic processes present in the growing chronologies was based on determining the possible quasi-periodic components and on a successive approximation of the series by polynomial models. Firstly, the spectral density of the time series was estimated by the maximum entropy method (Bartlett 1977, Mar- sden 1984, 1986). This method allows for the evaluation of the frequency areas according to their relative weight or importance. Secondly, these areas were filtered with narrow-band filters to damp fluctuations beyond a chosen band. This enables successfully distinguishing the narrower bands. They are then approximated with sinusoids. After separating out a sufficient number of periodic components and removing them up, it is possible to describe the course of the processes with precision.

Generalisations of the series, spectral analysis, expansion and approximation were made with the aid of software developed at the Laboratory of Dendrochronology, Institute of Plant and Animal Ecology, Ekaterinburg, and the University of Arizona, Tucson.

Methods}

In order to obtain long-term radial-increment series, living trees of varying ages as well as dead trees were cored at a height of 1.3 m. Sample trees generally formed the upper storey. Measurement series were cross-dated to produce unified time-series. Total ring widths were measured to the nearest 0.01 mm, and early- and late-wood widths estimated. Ring-width series and corresponding series of late wood percentage were obtained. The first ten annual rings were omitted.

The measurement series were divided by the corridor method developed by Shiyatov (1986). The corridor boundaries are represented by the gently sloping curves which show the maximum (upper) and minimum (lower) width of annual rings. The increment indices for each year were calculated with the following formula:

$$I(t) = \frac{X(t) - A(t)}{B(t) - A(t)}$$

where $I(t)$ is ring width in year $t$, $A(t)$ is current value for the lower boundary, $B(t)$ is current value for the upper boundary.

Indexing removes the age-produced changes, noise-related trends and other perturbations in the time series. In addition, standardisation allows for the estimation of mean-value functions (Cook et al. 1990, Schweingruber 1993). The mean index series, also called site chronologies, were produced by combining individual trees within each stand. The index series were generalised within the uniform conditions of the site and climate. When generalising for each calendar year, all the trees were checked, and the data were excluded which fell beyond the range of normal distribution at a 10% confidence level. When the current-year indices differed greatly from the normal distribution, the maximum mode was taken as a mean value. The 7 to 25 cross-sections from each of the 18 stands, enabled the construction of five generalised mean-value functions. Two master chronologies for the main research areas are presented in Fig. 1. The Kostomuksha Nature Reserve represents the north-taiga subzone, and the Vodlozero National Park represents the mid-taiga subzone.

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4. Results

Correlation between tree-ring series of individual trees forming the stand are of
great importance in determining the accuracy and reliability of the information ob­
tained. Various correlation-based techniques may be used to quantify the signal
strength of tree-ring chronologies (Briffa and Jones 1990). In even-aged closed
stands, the correlation coefficients between the increments of individual trees sol­
dom exceed the average of 0.4. Since codominant specimens were chosen for the
analysis, the effect of competition between trees can be neglected. Thus, the main
reason for differences in variability is due to the diversity in site conditions. On the
other hand, it is quite permissible to believe that codominant trees reflect the dy­
namics of stand productivity over long periods, because it is these trees that ac­
cumulate the bulk of wood.

Changes in radial growth depend mostly on variations in temperature, amount of
light and humidity. These factors, in combination with various site conditions, de­
termines the variability in tree-ring time series. Complex feedback links in the bio­
geocenosis also influence and smooth local conditions, which, in their turn, may
modify the dynamics of climatic factors common in the region. Although the total
The variance distribution of radial increment series shows the presence of similar length periods in the majority of stands studied (Tables 1 and 2), the temporal changes in these fluctuations make the general pattern seem like a "stochastic process."

The analysis of the bands of indices characterising the increment dynamics at each individual stand resulted in 15 to 23 distinct elementary periodic processes. Statistics for the stands located in the centre of southern Karelia (mid-taiga) are presented in Table 1, and those for the north-taiga subzone in Table 2. The main cyclic components are described by the length of periods, the amplitudes, the mean-square errors of approximation and the starting years. The error values indicate that the approximation of the frequency bands with sinusoids is quite satisfactory. Correlation between the estimations produced with the sinusoids and the source data range from 0.65 to 0.75 for various stands. In all, the selected sinusoids explain 42-45% of the total series dispersion. It should be borne in mind that no less than 40% of the total spectral power is made up by fluctuations from 2 to 8 years, and that narrow and sharp peaks (both positive and negative) are generally poorly estimated. The technique used here eliminates this drawback. However, biological interpretation of the fragmented cycles of lower than 5 years' duration is difficult.

The well-known 11-year period which is often connected with solar activity undergoes such changes in length and phase that it is not apparent when generalising the data on seemingly unified climatic conditions. However, it is clearly evident in the chronologies built for individual stands. The 22-23-year period, also known from historical sources, is quite distinct and maintains itself with only a 1-2-year shift in central Karelia. In the north-taiga, the occurrence of 18- and 25-year periods is approximately equal (Fig. 3), and in the eastern mid-taiga subzone, the spectrum expansion shows a power decrease in frequencies corresponding roughly to the

Table 1: Cyclic components of mean increment series in pine stands in the mid-taiga subzone.

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Period (years)</th>
<th>Mean-square error</th>
<th>Start year</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.695</td>
<td>85.366</td>
<td>3.640</td>
<td>1840</td>
</tr>
<tr>
<td>8.518</td>
<td>42.837</td>
<td>4.776</td>
<td>1835</td>
</tr>
<tr>
<td>14.738</td>
<td>21.040</td>
<td>7.489</td>
<td>1830</td>
</tr>
<tr>
<td>9.878</td>
<td>11.436</td>
<td>6.180</td>
<td>1835</td>
</tr>
<tr>
<td>10.506</td>
<td>9.485</td>
<td>4.196</td>
<td>1819</td>
</tr>
<tr>
<td>7.060</td>
<td>7.423</td>
<td>5.094</td>
<td>1808</td>
</tr>
<tr>
<td>6.255</td>
<td>6.089</td>
<td>2.668</td>
<td>1812</td>
</tr>
<tr>
<td>4.485</td>
<td>3.589</td>
<td>2.419</td>
<td>1810</td>
</tr>
<tr>
<td>5.336</td>
<td>4.672</td>
<td>3.382</td>
<td>1813</td>
</tr>
<tr>
<td>3.916</td>
<td>4.236</td>
<td>3.118</td>
<td>1811</td>
</tr>
<tr>
<td>3.136</td>
<td>3.908</td>
<td>2.235</td>
<td>1813</td>
</tr>
<tr>
<td>4.794</td>
<td>3.544</td>
<td>2.979</td>
<td>1813</td>
</tr>
<tr>
<td>3.631</td>
<td>3.775</td>
<td>3.466</td>
<td>1810</td>
</tr>
<tr>
<td>2.688</td>
<td>2.625</td>
<td>2.650</td>
<td>1810</td>
</tr>
<tr>
<td>2.837</td>
<td>2.571</td>
<td>2.305</td>
<td>1810</td>
</tr>
<tr>
<td>1.105</td>
<td>1.033</td>
<td>1.153</td>
<td>1810</td>
</tr>
</tbody>
</table>

Table 2: The main spectral peaks in increment series of the north-taiga stands.

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Period (years)</th>
<th>Relative length (years)</th>
<th>Start year</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.695</td>
<td>85.366</td>
<td>1840</td>
<td></td>
</tr>
<tr>
<td>8.518</td>
<td>42.837</td>
<td>1835</td>
<td></td>
</tr>
<tr>
<td>14.738</td>
<td>21.040</td>
<td>1830</td>
<td></td>
</tr>
<tr>
<td>9.878</td>
<td>11.436</td>
<td>1835</td>
<td></td>
</tr>
<tr>
<td>10.506</td>
<td>9.485</td>
<td>1819</td>
<td></td>
</tr>
<tr>
<td>7.060</td>
<td>7.423</td>
<td>1808</td>
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</tr>
<tr>
<td>6.255</td>
<td>6.089</td>
<td>1812</td>
<td></td>
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<tr>
<td>4.485</td>
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<td>5.336</td>
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</tr>
<tr>
<td>2.837</td>
<td>2.571</td>
<td>1810</td>
<td></td>
</tr>
<tr>
<td>1.105</td>
<td>1.033</td>
<td>1810</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Temporal shifts in cyclicity of 22 and 50 years in length in the north- and mid-taiga subzones.

Results 35
22-year period. For estimations of the dynamics of forest productivity, the increment fluctuation with periods between 40 and 60 years and about 100 years appear most promising. They are least dependent on the growth conditions in individual stands and more influenced by regional climatic peculiarities. Nonetheless, a temporal shift, as long as 30 years, between stands in the north- and mid-taiga is observed, in addition to a 50-year fluctuation (Fig. 3).

In order to investigate cycles of 100 years in length, the length of the chronologies must be at least 300 years. It is not certain whether or not such fluctuations even occur at all in the dynamics of any natural phenomena. Repeatability, or close similarity, of the main periods in the dynamics of various environmental factors is evidence for regularities in their course. In addition to the information on radial increment series, also other processes were analyzed to investigate the possibility of finding corresponding cycle components. This analysis included zonotic data on solar activity in vegetation periods (Wolf's number), average monthly temperatures of the growing season and the amount of rainfall in July. In Table 3, the spectral characteristics of these processes are presented. The forms of these factors and increment dependency are complex.

The 91-year cycle is in the Wolf's number fluctuation for summer. So, the presence of fluctuations similar to it must not be ruled out even from the increment series not longer than 300 years. Preliminary analysis of the data obtained shows a noticeable increment decrease coinciding with a 50-year cycle. A most marked decrease occurs when long and middle-length cycle components simultaneously reach their minimum. In the current century, the deep increment minimum took place around 1960 in the north taiga, and around 1990 in the mid-taiga. Comparing the increment dynamics in different stands shows that the site quality is of primary importance in the shift. The lowest levels of increment variability in the mid-taiga sub-zone are close to the characteristic levels of variation in the north taiga (Fig. 4).

Large variability in increment series makes the search for links difficult. In this respect, the analysis of late-wood content in annual rings seems promising. The late-wood content is affected greatly by hydrothermal conditions and its range of natural variability is much less. The dynamics of the late-wood content is stable to a considerable extent. This is evident in different spots in Karelia and, at the same time, there seems to exist a possible connection with changes in solar activity (Fig. 5). It is reasonable to expect the curves of radial increments and late-wood contents to reflect at least the main inflection points, since it is common knowledge that a decrease in the annual ring width is necessarily accompanied by an increase in the late-wood content. However, some natural deviations from this relation might take place due to different combinations of soil and climate conditions.

Forecasting the radial dynamics in Figure 4 is based on the assumption that if simple periodic process has taken place in the course of several complete cycles, then it may last for at least the next whole cycle. Apart from this, the link between biological phenomena and periodic processes including movements in space, lasting thousands of years and staying almost unchanged, support this idea. After having reliable harmonic constituents, the forecasting of increment dynamics is done by summing them up at a defined span of time. Naturally, the longer the series of available observations, the more reliable is its extrapolation by polyharmonic model.

### Table 3. The mean spectral peak in the series of manufacture and solar activity

<table>
<thead>
<tr>
<th>Period range (year)</th>
<th>Period length (year)</th>
<th>Mean monthly temperatures of run in July</th>
<th>Wolf’s number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td></td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>25-50</td>
<td>25.00</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>15-25</td>
<td>15.00</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>5-10</td>
<td>5.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2.5-5</td>
<td>2.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>2.0-4</td>
<td>2.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
</tbody>
</table>

5. Discussion and Conclusions

The problem of changing forest productivity (Spiecker et al. 1994) includes two crucial questions concerning (1) the anthropogenic impact and (2) the natural development. To answer the first question seems impossible without investigating the other. If these changes do have a cyclical character, they may be used in forecasting the main trends in wood increment dynamics.

In the present work, the occurrence of about 18- and 25-year periods was detected in the north taiga. In the central mid-taiga subzone, roughly 22-year and 50-year fluctuations were evident. The long-term increment dynamics of stands growing at their distributional limits have been investigated in numerous studies (e.g., Douglass 1919, Briffa and Schweingruber 1992, Graybill and Shiyatov 1992). Dealing with northern European tree-ring data, Briff and Schweingruber (1992), as well as Si-rov and Hat (1973), both found concentrations of variances corresponding to cycles
with periods of about 3.6-33.0 and 80-96 years. By far the most significant peaks in the temperature reconstructions of Briffa and Schweingruber (1992), however, correspond to a period between 33 to 38 years.

Burroughs (1994) has reviewed dendrochronological literature in a search of evidence of cycles. He concludes that there is generally some support for the 11-year (sunspot) cycle, and, more importantly, substantial evidence for the 20-year cycle. According to the above author, the tree-ring evidence does not distinguish between this being the 18.6-year lunar cycle or the 22-year double sunspot cycle. There exists also strong support for 80- to 90-year and 180- to 200-year cycles.

The present work is an attempt to predict the baseline trend in current tree growth. However, cyclicity in increment series is such a complex phenomenon that no definite conclusions can be made about productivity changes over great areas.
Growth Trends of Scots Pine (*Pinus sylvestris*, L.) in Unmanaged and Regularly Managed Stands in Southern and Central Finland

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Abstract

Annual ring data collected from strict nature reserves and long-term permanent plots of the Finnish Forest Research Institute (METLA) did not reveal any long-term trend in the radial increment of Scots pine (*Pinus sylvestris*) in the southern part of Finland during the last 100 years. This result was supported by the analysis of standwise increment data from permanent thinning experiments. The height development of dominant sample trees had been faster than that of previous site index curves. This was supposed to be mainly due to differences in the data of this study and of the index curves. According to our investigations, there were some indications of increasing productivity on some sample plots in the southernmost part of the country during the last 40 years.

Possible reasons for non-existing growth trends are as follows:

1. The wide climatic variation of tree growth in northern latitudes could conceal the possible trend. The years 1961-1990 were slightly cooler than the years 1931-1960 in Finland.

2. The SO2- and N-depositions in Finland during the past few decades have been too low to be able to cause growth trends of such magnitude that could be separated from natural growth variation.

3. The study material consists of untreated stands or stands with known management history. Thus, trends caused by changing silviculture are outside the scope of this study.

On the basis of the non-existing trends in this study and results from eight successive national forest inventories beginning as early as in the 1920s, it can be concluded that the main factors leading to a 44% increase in the total growth of Finnish forests during the last four decades are changes in stand structures (age, density) and silvicultural practices (regeneration, thinnings, drainage, fertilization).

References


*European Forest Institute Research Report No. 5*
1. Introduction

1.1. Growth Trends in Individual Trees and Forest Stands

The total growth of Finnish forests has increased by more than 40% during the last 40 years. This can be observed in the measurement data collected in the course of national forest inventories (NFIs; Tomppo and Siitonen, 1991). The main cause for the increased productivity is supposed to lie in the intensified silviculture practiced for more than four decades, sustainable wood production being the main target. The chief growth-promoting measures carried out were the draining of peatlands, the rejection of selection cutting and higher densities in young and mature stands.

In addition to this man-made increase in stand growth, trees have also shown some deviation from expected growth. Hari and Arovaara have reported evidence of increasing growth trends for Scots pine in the 1900s (1984, 1988) and Henttonen (1990) for Norway spruce from 1970 to 1985. According to the study by Henttonen, the short-term increase in the productivity of Norway spruce correlated with increasing temperature and precipitation during that period.

Most yield tables used in forest management in Finland are based on measurements carried out before 1960. Quite often, the measured growth levels of stands today exceed yield table estimates. The site type, estimated using the species composition of the ground vegetation (Cajander 1909), has in some cases improved by one class during the duration of experiments begun in the early years of the century. The proportion of forests dominated by bilberry (Vaccinium myrtillus - fertile site) has also increased and the proportion of cowberry (Vaccinium vitis-idaea - poor site) has decreased according to the inventory results from the past 40 years. It is not yet clear whether the abundance of bilberry is due to changes in stand structures (density and age) or to improving soil fertility.

Clear decline in tree growth and even increasing mortality have been observed around industrial plants for decades. The negative effect of pollutants on tree growth has, in extreme cases in Russia, been observed as far as at distances of 30 to 40 km from pollution sources in Russia (Novaj and Reams 1995). The said damage is possibly caused by gaseous compounds acting on needles or by the indirect effects of sulphur and heavy metals on the soil.

1.2. Environmental Changes

Chemical compounds emitted into the atmosphere as the result of human activity have markedly altered the properties of the air, the soil, and the water. The concentration of atmospheric $SO_2$ in Finland is clearly at a lower level than in Central Europe. In the 1980s, the emissions of $SO_2$ in Finland decreased by 60% (Fig. 1).

During the last few decades, nitrogen deposition has been observed in amounts varying from 2 to 6 kg N ha$^{-1}$ year$^{-1}$ in central and northern Finland (Knievel et al., 1991). The said damage is possibly caused by gaseous compounds acting on needles or by the indirect effects of sulphur and heavy metals on the soil.

Clear decline in tree growth and even increasing mortality have been observed around industrial plants for decades. The negative effect of pollutants on tree growth has, in extreme cases in Russia, been observed as far as at distances of 30 to 40 km from pollution sources in Russia (Novaj and Reams 1995). The said damage is possibly caused by gaseous compounds acting on needles or by the indirect effects of sulphur and heavy metals on the soil.

The third gas affecting tree growth is $CO_2$, the increase of which is supposed to promote global warming in future decades. Both temperature and $CO_2$ influence tree growth. These two growth factors are expected to enhance the biomass production of Finnish forests in the future.

On the basis of the above facts, it can be assumed that part of the increase in forest growth in Finland during the last 40 years may be attributed to environmental changes. Contrary to the greenhouse theory, the mean temperature of the growing season in Finland during the last 30 years has been lower than in the period 1931-1960. This may partly counteract the expected increase in forest productivity.

The aim of this study was to find out if Scots pine trees in Finland presently grow at the same rate as pines of the same size or age in earlier times. The analyses were done using increment cores obtained from strict nature reserves (Natura Parks) or from old permanent sample plots established by the Finnish Forest Research Institute in the southern part of the country.
2. Material and Methods

2.1. Old Trees Measured in Strict Nature Reserves

To get an overview of past long-term trends, the first study focused on untreated Scots pine stands on relatively poor sites in Southern and Central Finland. Scots pine was selected as the study object because most old pine stands were established after forest fires on open land. Consequently, the growth history of the studied trees has been quite regular without any suppression phases caused by the overstory in youth.

In order to estimate the mean growth level of trees prior to the era of atmospheric depositions, pine stands, 100 to 200 years of age, were sampled. The sampling was quite similar to that done by Hari and Arovaara (1984). The biggest problem with the material is the unknown stand history. Competition between trees in their youth causing growth decrease and natural mortality, and frequent forest fires bring uncertainty into the interpretation of the results. Trees surviving partial forest fires can provide us with long growth trends, thanks to decreasing competition and the irregular healing of scars made by fire. Stands with visible traces of forest fires were rejected as study objects.

The material measured in strict nature reserves consisted of fourteen stands on poor sites in Southern and Central Finland. From each subjectively selected research plot, ten dominant or co-dominant trees closest to the plot centre were bored to the pith from their south and north sides. The size of this material was 207 cores. The measured tree age at breast height was between 98 and 200 years (mean 151 years); the corresponding diameter was between 17.4 and 43.3 cm and the total number of annual rings was 30,545.

The material, based only on increment borings without any information on stand history, is suitable for simple analyses. The only characteristics known throughout the entire lifetime of the trees are the age, diameter, and radial increment for each year. Analysing this type of data can provide some indication of the possibility of the existence of growth trends, but not prove it.

2.2. Long-Term Experiments

Based on Stand Increment

The known management history of stands makes the results of analyses much more reliable because of the possibility of modelling the effects of competition. In this respect, the best possible data can be found on the permanent experiments, the first of which were established in the 1920s by the Finnish Forest Research Institute. Increment data of individual trees combined with stand characteristics, measured every 5 to 10 years, markedly improves the reliability of the trend estimation.

The standwise material consists of experiments begun in the 1950s and 1960s in order to study the growth reactions of whole stands after low thinning and fertilization. Thinned control plots without fertilization were used in this study. The total number of stand plots measured was 98.

Based on Individual Trees

The most reliable picture about growth trends and causes for trends can be obtained by conducting single-tree analyses in stands whose history is known exactly. This type of material can be obtained by taking increment cores or discs from trees growing on successively measured permanent plots.

Taking increment cores from standing trees damages them and makes them susceptible to rot. In this study, the sample trees were cored only in the study stands which were no longer objects of active research. In order to guarantee a balanced...
Results

3. Results

3.1. Growth at a Stand Level

The trend in stand increment was studied using the growth model presented by Nyyssonen and Mielikainen (1978), which was based mainly on data from the 1940s and 1950s. The model predicts the volume increment of a stand for the following 5-year period as a function of forest site type, stand age, volume, and mean diameter.

The mean diameter as a predictor variable is important for detecting possible growth trends. The correlation between stand age and mean diameter can conceal a trend if the growth model is based only on stand age and volume. Rejecting the mean diameter as one predictor variable decreases the significance of forest site type as a dummy variable. In the worst case, this can change the coefficient of this variable negative.

The growth model used was

\[
\ln I_{V5} = -0.5885 - 0.09667 \times (\ln T)^2 + 1.2503 \times V^{(1/V)^{0.3}} + 0.1796 \times (\ln D)^{8/10} + \text{constant},
\]

where

- \( T \) is stand age, years,
- \( V \) is stem volume, m\(^3\)/ha,
- \( D \) is mean diameter (median of basal area), cm,
- \( \text{constant} = 0.702 \), if the forest site type is Calluna Type.
The existence of a trend was investigated by comparing the measured volume increment of the experimental stands to the model estimates. First, the mean of the model estimates was calibrated to correspond to the growth level of the data. The presence of a trend could then be revealed by examining the residual deviations from model estimates against the calendar year.

The residual variation of stand volume increment around the model estimate (Fig. 4) does not show any trend in stand growth from 1950 to 1990. This result does not guarantee the absence of a long-term growth trend. Climatic growth variation can interfere with the comparisons during the relatively short observation period of 40 years. On the other hand, the use of periodic 5-year increments smooths annual variation.

### 3.2. Growth of Individual Trees in Strict Nature Reserves

The radial increment of sample trees in different age classes for each calendar year does not show the presence of a long-term trend during the last 50 years. The favorable years (1957, 1967 and 1990) can be observed in all age classes in the same way as the years of low growth (1942, 1956 and 1985, Fig. 5).
A more detailed analysis was made by trying to model the radial increment of sample trees and studying the residual variation of the data against the calendar year. In the model, the width of a single annual ring was predicted by tree diameter as the only predictor variable. Tree age was not used because it could, when used together with diameter, conceal a possible trend (Elfving and Tegnhammar 1995). This is because the size of a tree at a certain age is a measure of soil productivity itself.

In order to make the age and diameter distribution of the material as homogeneous as possible against the calendar year, the data was first restricted to contain only annual rings in age classes from 90 to 120 years, diameter classes 16 to 28 cm and the calendar years 1893 to 1992 (Fig. 6). Without this, the data may have been skewed (correlation between diameter and calendar year), causing problems in growth modeling and interpreting of the results.

The restriction of the data resulted in a growth model with a zero coefficient of determination ($R^2$). This means that the width of annual rings in the age class 90-120 years has been constant in unmanaged stands for the last 100 years. The deviation of the radial increment from the mean (Fig. 7) along the calendar year shows both short- and long-term growth variation during this century. A slight descending trend ($p = 0.04$, $t = -2.38$) could be detected for the whole study period. This trend may be caused by the lower mean age of annual rings in the data before 1920 (see Fig. 6). From 1943 to 1992, no trend exists. In this respect, the results dil-

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**Fig. 6.** The radial increment of Scots pine in different age classes in the material from strict nature reserves. Age classes 115, 125, 135 and 145 years.

**Fig. 7.** The deviation of the radial increment from the mean along the calendar year.
for clearly from those published by Hari and Arovaara (1984), who used the same kind of data from untouched stands. The method used by Hari was based on the increment curve against age from the 19th century as reference. Some uncertainty in both studies is caused by possible human influence in the past. Most of the strict nature reserves were set aside as late as the 1950s, and consequently their management history is not always exactly known. So some of the annual rings in the first few decades of this century may have been influenced by selective cutting, commonly used in those times.

3.3. Individual Trees on Permanent Experiments

Regular measurements of trees on permanent experiments offered a good basis for modelling the effects of competition on tree growth. The method was roughly the same as was used with the material from strict nature reserves. Prior to modelling, the material was limited to 30-60 years in age. This limitation decreased the variation in the material and thus resulted in a growth model with a very low degree of determination. The study could also have been made on the basis of existing growth models. This alternative was rejected because the models contained tree age and diameter as predictor variables (see Elfving and Tegnhammar in this volume).

\[
\begin{align*}
\text{Ring width (mm)} & = 1.804 + 0.00357 \cdot d + 0.0000701 \cdot N + 0.05301 \cdot G + 0.0000916 \cdot G^2 + 0.1043 \cdot H_d + 0.04071 \cdot D_g \\
& \text{where } d = \text{tree diameter (cm)}, N = \text{number of stems per ha}, G = \text{stand basal area (m}^2\text{ ha}^{-1}), H_d = \text{mean height (m)}, D_g = \text{mean diameter (cm)}. \text{Height and diameter weighed with basal area.} \\
\text{Constant} & = 1.804 \text{ if site type CT (H100 = 21)} \\
\text{Constant} & = 1.987 \text{ if site type VT (H100 = 24)} \\
\text{Constant} & = 2.327 \text{ if site type MT (H100 = 27)} \\
\end{align*}
\]

\[\text{Number of observations} = 5354\]
\[\text{Degree of determination} R^2 = 0.22\]

The deviations from the model do not show any long-term trends from 1924 to 1992 (p = 0.1653, t = -0.21). The small differences between the results from strict nature reserves and from permanent experiments may be caused by the relatively small number of samples in both materials (Fig. 8).

3.4. Height Development of Dominant Trees

The development of dominant height is regarded as one of the best stand characteristics for showing changes in soil productivity because dominant height is considered to be insensitive to the management history (density) of the stand. In this study, the site index of every stand was calculated at different dates on the basis of felled sample trees. The model, based on data from national forest inventories from the beginning of the 1950s (Gustavsen 1980), is well suited for this study because it cannot contain the possible growth trend during the past 40 years. In Fig. 9, the relative site indices (year 1950 = 1) for felled sample trees calculated using the model presented by ...

\[\text{Relative site index = coefficients of } d \text{ and } N \text{ variables adjusted to } t = 0 \text{ in the model.} \]

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4. Discussion and Conclusions

The results obtained contain many uncertainties. The long-term climatic variation of tree growth is one of them. The acute effect of exceptional climatic events can lead to long-lasting growth decline as a result of root damage and defoliation (Jalkanen et al. 1985). The recovery of and decreasing competition between surviving trees after catastrophes or management measures can result in very long-lasting trend-like growth reactions.

The major weakness of the data from old stands of strict nature reserves is the lack of information on stand history. Forest fires have occurred in pine stands in southern Finland at intervals of 60 to 100 years (Parviainen 1994). The signs of fires, storms and old cuttings may have disappeared elsewhere, but not from annual rings. Fire has presumably caused long-lasting trends in the annual rings of some old trees in this material. The initial density of the study stands has also played a decisive role in the competition between trees, natural mortality and diameter growth of the stands in their youth.

The problems in connection with permanent experiments are the relatively small size of the data sample and the uneven age structure of the data. The material is concentrated at the beginning of this century in young and at the end of the century in old age-classes. The study method presupposes that the age structure of the annual ring material remains constant throughout the century. To solve this problem, the material was limited to age classes from 30 to 80 years. In addition to old experiments, also experiments established during the last few decades were included in the material. This in turn results in variation caused by annual rings originating from different stands in each calendar year.

A problem common to all materials is that of site classification. If there is a growth trend, this trend is included in the site class, regardless of whether the clas-
Natural forest and old experiments do not reveal trend-like changes in tree growth. Only few indications about trends could be found on some plots in the southernmost part of the country. The following are some of the reasons for the lack of trends:

1. In northern latitudes, the typically marked climatic variation in tree growth can conceal small emerging trends.
2. The temperature and precipitation of the growing season do not show a clear trend during this century. The summers of 1961-1990 were slightly cooler than those of the preceding 30 years. Only the temperature of May is showing an increasing trend during the past few decades.
3. The fairly low nitrogen deposition rate (5 kg ha⁻¹ a⁻¹) in Central Finland during the past 20 years is unlikely to cause growth trends that could be separated from long-term growth variation.
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4. The study material consists of unmanaged natural stands and experimental stands that have been subjected to low thinnings. Thus, trends caused by changing silviculture are outside the scope of this study.

On the basis of the non-existing growth trends of this study and the results obtained from eight successive national forest inventories, it can be concluded that the main factors leading to a high increase in the total growth of Finnish forests during the last 40 years are the results of changes in stand structures (age, density etc.) and silvicultural practices (regeneration, thinnings, drainage, fertilization etc.).

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References


"Trend":
+ positive
- negative
0 no trend
ps preliminary study