EFFECTS OF CLIMATE ON THE GROWTH OF SCOTS PINE IN THE SAIMAA LAKE DISTRICT, SOUTH-EASTERN FINLAND, IN THE SOUTHERN PART OF THE BOREAL FOREST BELT
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Key-Words: Scots pine, south boreal zone, growth variability, growth responses.
Parole chiave: Pino silvestre, zona sud boreale, variabilità di accrescimento, risposte di accrescimento.

Abstract

Scots pine chronologies for the southern part of the boreal belt in Finland were constructed and climate/growth relationships calculated. Precipitation seems to be more important for tree growth in this area than temperature, particularly between April and July.

1. Introduction

1.1. Background

Published tree-ring chronologies for the southern parts of the boreal zone are rare when compared to dendroclimatological research activities in the forest-limit region of Fennoscandia (e.g., ANIOL, ECKSTEIN 1984; BRIFFA ET AL II 1990, 1995; LINDHOLM ET ALII 1996). The scarcity of tree-ring chronologies in the southern region does not reflect a scarcity of forests, but the scarcity of natural stands and the difficulty in extracting an unambiguous environmental signal from tree-rings of closed canopy forests. Some of the main reasons for the lack of common growth patterns (or 'signal') are anthropogenic and may be traced back to the history of land use and forestry practices in the region. Slash-and-burn cultivation, also termed swidden or burn-beating, was the most widely practised cultivation technique in eastern Finland prior to the 1900s (HEIKINHEIMO 1915; GRÖNLUND 1995). In addition, during the present century forests have been intensively managed.

A common signal in tree-ring timeseries is not only evident under extreme conditions, such as those prevailing in northern forest-limit regions, where conifer tree-ring growth is strongly linked to temperature variability from year to year, but also in more moderate climates. Tree-ring chronology networks have been established in various habitats, in semiarid zones as well as in humid, temperate and cold regions all over the world (Fritts 1976; HUGHES ET ALII 1982; JACOBY, HORNBECK 1987; SCHWEINGRUBER, BRIFFA 1996). The present work represents
our contribution to these networks and a first attempt to model climate/tree-growth relationships in the southern parts of the Finnish boreal forest belt.

Compared to the northern timberline, it is reasonable to expect tree-growth in the south to be less affected by growing season temperatures, and more affected by, for example, precipitation. In addition, going from the north to the south, factors related to stand dynamics, like competition, play an increasing role in controlling annual growth variability of conifers. Towards the south, the correlations between the diameter growth of Scots pine and climate variables are expected to weaken. Likewise, the variation in the width of the annual rings should become smaller.

1.2 Aims

The primary objectives of this research were to:

1. develop areal ring-width chronologies and a regional master-chronology for the Saimaa lake district, south-eastern Finland, the south boreal forest zone;
2. study the origin of the variability in the chronologies;
3. determine which climate variables have the strongest influence on pine growth;
4. establish a basis for dendrochronological dating in eastern Finland: An increasing number of samples from historical, wooden buildings in the region have been gathered, enabling a possible temporal extension of the previous chronology;
5. create a basis for the analysis of forest health using dendroecological techniques to assess the rate, timing, and magnitude of changes in growth rates; and
6. compare the final chronology with those developed in northern Fennoscandia.

It is clear that the results of research at only a couple of sites will not be sufficient to identify or isolate forcings affecting an entire region. It is necessary to develop a network of sites throughout the region and to investigate in detail the climate/pine growth relationship at each of them, because topography, soils, disturbances, species composition, climate, and anthropogenic influences are not homogeneous throughout south-eastern Fennoscandia. Each site, therefore, should exhibit subtle differences in the climate/pine growth relationship. Only by investigating the effects of such site heterogeneity over a network of sites and synthesising results throughout a larger region, can we begin to isolate meaningful growth forcing factors.

2. Research area and material

2.1 Research area

The research area covers a region surrounding the central parts of the Lake Saimaa basin, between 29°-30°E and 61°-62°N, in the province of South Savo, in eastern Finland (Fig. 1). The region lies within the south boreal forest zone (AHTI ET ALII 1968) and forests cover more than 80 per cent of the terrain today. The region is part of the Vuoksi lake and river system, and the landscape is dominated by the Saimaa Lake Complex and the thousands of small lakes that drain into this large lake basin. The Vuoksi outlet channel allows the waters to drain into Lake Ladoga and further to the Gulf of Finland.

Most of the bedrock in the region is covered by glacialic till, but bare bedrock terrain occurs frequently around the shores of Lake Saimaa. Fine-grained soils are relatively scarce and small compared to the agricultural areas of southern and western Finland with their extensive clayey soils. The topography around Lake Saimaa is characterised by high relative altitudes, due to the unevenness of the bedrock and glacialic features such as drumlins and eskers (SEPPÄLÄ 1986).

In the study region, birch is still relatively more abundant and spruce relatively less abundant than in the more western parts of Finland. This is due to slash-and-burn cultivation that was still practised in eastern Finland in the early 1900s (HIKINHEIMO 1913; KIVEKÄS 1939; AARNE 1994; GRÖNLUND 1995). A major change in the vegetation cover is evident in the pollen stratigraphies from the 16th century onwards, involving a decline in the mature forests and the generation of an open landscape. This change was due to an expansion in the areas exploited for slash-and-burn agriculture (GRÖNLUND 1995; LEHTONEN 1997).

2.2 Tree-ring data

Ten areas in all were studied in the cen-
The central part of the Saimaa lake district, in eastern Finland (Fig. 1). 240 trees in all were sampled by taking two increment cores from each. Maximum distance between the sampled stands is about 50 km. Site information and associated tree-ring statistics are presented in Table 1. Seven of the sampling sites are located on islands of Lake Pihlajavesi, which is part of the Saimaa Lake Complex. One site lies on the narrow ridge of Punkaharju, which is flanked on both sides by lakes. Two sites are located on mainland, one very close to the town of Pihlajavesi, which is part of the Saimaa Lake Complex. One site is likely to have experienced more human influence in the form of recreational activities than the other areas. The intention was to study 'natural' stands, those least affected by influences of forest management. It was presumed that forest stands on islands would have escaped the most intensive forestry practices and slash-and-burn agriculture. Dry sites and old trees were selected where possible. Old age was considered to be recognisable in terms of large stem diameter, tapered trunk, large branches, flat crown top, and dominant position among surrounding trees.

2.3 Climatic data

We have used climate data from a meteorological station at Punkaharju, which is located in close proximity to the Punkaharju vonlinna. This site is likely to have experienced more human influence in the form of recreational activities than the other areas.

The intention was to study 'natural' stands, those least affected by influences of forest management. It was presumed that forest stands on islands would have escaped the most intensive forestry practices and slash-and-burn agriculture. Dry months precipitation totals and averaging mean monthly temperatures over various intervals from April to September.

3. Methods

3.1 Ring-width measurement and cross-dating

At each stand, two cores were extracted at breast height from between 20 and 40 trees by a standard increment borer. Ring widths were measured to the nearest 0.01 mm. Data quality was assessed by visual comparison of ring-width graphs on a light table and by computing cross-correlations between individual series and a master chronology for each stand. All segments of cores identified as having unusual values or significant (p < 0.05) lagged correlation with the master chronology were visually re-checked and either corrected or eliminated from further analyses. This procedure resulted in the elimination of less than 2% of the cores from the analysis.

3.2 Chronology development

Before averaging the dated ring-width series into chronologies, they are usually standardised in order to stabilise the variance and the mean (Fritts 1976; COOK et alii 1990). We applied a pragmatic approach in standardisation, which is expected to reduce nonclimatic sources of variation (noise) in the data (BRIFFA et alii 1996). It is assumed...
that the removed low frequency variance consists mainly of noise, however, there is a potential loss of meaningful long timescale variance. We used fitted splines, passing 50% of the variance of the series at frequencies greater than two thirds of the series length (Cook, Peters 1981). In addition to age trends, biological persistence, and long-term stand dynamics, nonclimatic variance in ring width arises as a result of disturbance either to individuals (e.g., pathogens) or to entire stands (e.g., fire, grazing) (Fritts, Swetnam 1989; Cook 1990).

The low-frequency, non-climatic trends in growth were modelled by fitting cubic smoothing splines to each series using the ARSTAN procedure developed by Cook (Cook 1985; Holmes et al. 1986; Cook et al. 1990). We have used 'standard' as well as 'residual' chronologies produced by the ARSTAN procedure. Standard versions of the chronologies were formed by dividing the observed ring-width values by the modelled ring-width values for each core series. Indices for individual cores were then averaged together producing several site chronologies and a regional chronology. Residual chronologies were also produced by averaging, however here the indices are the results of autoregressive modelling of the detrended series, containing approximately equal amounts of variance at all wavelengths (Cook 1985; Cook et al. 1990). These 'white noise' series are expected to have a strong common signal without persistence.

### 3.3 Descriptive statistics

Several descriptive statistics were calculated for each chronology to allow comparisons among the chronologies analysed in this study as well as to permit comparisons with other dendroclimatic data sets (Fritts 1976; Briffa, Jones 1990). We have employed standard deviation (SD), mean sensitivity (MS), and first-order autocorrelation coefficient ($r_1$) measures. We have also used the chronology signal-to-noise ratio (SNR) as a measure of the common variance in a chronology scaled by a measure of the total variance of the chronology (Wigley et al. 1984; Briffa, Jones 1990). The ratio is reported here to facilitate comparisons with published chronologies. As an alternative, the variation held in common among the cores that compose the chronology were assessed by the percentage of variation explained by the first principal component of the correlation matrix of the core series that is defined over a common time interval.

#### 3.4 Determining tree-growth responses to climatic factors

We used two techniques to assess the climatic influence on the growth of Scots pine (e.g., Briffa, Cook 1990). First, we performed regression analyses between monthly and seasonal precipitation and temperature data and the residual chronologies of pine growth (Cook et al. 1990). The climate variables were also lagged to determine whether climate during the previous growing season, beginning in July, affects pine growth during the concurrent growing season. Second, we used 'response function' analysis (Fritts 1976; Briffa, Cook 1990), a more robust analysis that minimizes effects due to multicollinearity among variables. In this analysis, climatic data spanning the months from the previous July to the current August are first orthogonalized, then entered into a multiple regression with the standard index chronology as the dependent variable. Because the regional chronology used here was highly autocorrelated, three new variables representing growth from the three previous years were created by lagging the chronology, and also included in the response function analysis (Fritts 1976).

The number of predictors in the pool of principal components was reduced in two phases. First, the so-called PVP method was used (Guot et al. 1982; Guot 1985, 1990). This means that only those components were retained whose cumulative product of eigenvalues equaled or exceeded 1. A further reduction was accomplished by the method of entering predictor variables in the regression analysis based on t-tests (Briffa et al. 1983, 1986). Only variables with t-values greater than 1 were retained for further analyses. The produce progressively improves the regression equation. Since the PCs are orthogonal, each regression coefficient may be calculated independently using simple regression techniques. The resulting regression equation contains the weights (coefficients) for each of the original climate variables. The standard error for each monthly coefficient was calculated to determine the 95% (two standard error) confidence interval for each month in the response function. Any weight significantly different from zero indicates a month in which precipitation or temperature significantly affects pine growth.

### 4. Results

#### 4.1 Chronologies

**Description of the chronologies**

We were able to build areal chronologies only for six out of ten stands in all. At present, we have no explanation why the measurement series from the four sites could not be matched with the rest of the data (cf. Table 1). Measurement series from individual trees from two sites, Kietävänvirta (9) and Kalliossaari (10) correlated poorly with each other, and could not be either cross-dated or averaged together. Trees from Kaupinsaari (7) and Mäntyrinne (8) produced site chronologies, but they could not be matched with the rest of the chronologies. The chronology statistics for the six feasible sites are compared in Table 2.

<table>
<thead>
<tr>
<th>Study site</th>
<th>MS</th>
<th>SD</th>
<th>$r_1$</th>
<th>$r_{max}$</th>
<th>SNR</th>
<th>%PC1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punkaharju</td>
<td>0.148</td>
<td>0.172</td>
<td>0.388</td>
<td>0.401</td>
<td>1.89</td>
<td>43.1</td>
</tr>
<tr>
<td>Kyyröniemi</td>
<td>0.131</td>
<td>0.207</td>
<td>0.634</td>
<td>0.493</td>
<td>2.98</td>
<td>52.8</td>
</tr>
<tr>
<td>Eteläsaari</td>
<td>0.167</td>
<td>0.216</td>
<td>0.546</td>
<td>0.485</td>
<td>2.79</td>
<td>51.2</td>
</tr>
<tr>
<td>Sauvassaari</td>
<td>0.194</td>
<td>0.289</td>
<td>0.612</td>
<td>0.474</td>
<td>1.81</td>
<td>51.0</td>
</tr>
<tr>
<td>Pitkäsaaari</td>
<td>0.211</td>
<td>0.266</td>
<td>0.506</td>
<td>0.334</td>
<td>1.13</td>
<td>41.6</td>
</tr>
<tr>
<td>Huvilassaaari</td>
<td>0.258</td>
<td>0.369</td>
<td>0.577</td>
<td>0.489</td>
<td>1.82</td>
<td>53.9</td>
</tr>
</tbody>
</table>

MS=mean sensitivity, SD=standard deviation, $r_1$=first order autocorrelation, $r_{max}$=mean-tree correlation mean (Wigley et al. 1984), SNR=signal-to-noise ratio, and %PC1=percentage variance explained by the first principal component.
High and low frequency variation seems to be present in the same series. Site number 2, Kyrönniemi, has the lowest mean sensitivity value and highest value of first order autocorrelation, mean tree correlation mean and signal-to-noise ratio. It is noteworthy that this is the site closest to urban influence, the town of Savonlinna. In general, the statistics indicate that the data analysed here do not show any consistent patterns relative to geographical location.

Growth variability of Scots pine in south-eastern Finland

Fig. 3 and Table 3 demonstrate that there exist common features in both high and low frequencies among the six site chronologies. In Fig. 3, common patterns are evident already during the last century. At the turn of the 19th and 20th centuries, there is a short period of low growth at all sites. This depression is generally over after the 1910s, and during the 1920s these southern pines experienced a peak in growth. During the 1940s there exists a growth minimum at most sites, and the 1950s show good growth. During the last two decades growth has been generally increasing.

Comparison of growth variability between the south-eastern and northern forest-limit regions

In Fig. 4, the south-eastern chronology is compared with the regional chronology built for the northern Finnish forest limit.

<table>
<thead>
<tr>
<th></th>
<th>Punkaharju</th>
<th>Kyroinnemi</th>
<th>Eteissaari</th>
<th>Sauvasaari</th>
<th>Pitkaaari</th>
<th>Huvilasaari</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td>0.489</td>
<td>0.460</td>
<td>0.275</td>
<td>0.408</td>
<td>0.488</td>
<td>0.353</td>
</tr>
<tr>
<td>3</td>
<td>0.297</td>
<td>0.498</td>
<td>0.547</td>
<td>0.335</td>
<td>0.289</td>
<td>0.504</td>
</tr>
<tr>
<td>4</td>
<td>0.563</td>
<td>0.419</td>
<td>0.547</td>
<td>0.335</td>
<td>0.289</td>
<td>0.504</td>
</tr>
<tr>
<td>5</td>
<td>0.470</td>
<td>0.498</td>
<td>0.547</td>
<td>0.335</td>
<td>0.289</td>
<td>0.504</td>
</tr>
<tr>
<td>6</td>
<td>0.289</td>
<td>0.504</td>
<td>0.547</td>
<td>0.335</td>
<td>0.289</td>
<td>0.504</td>
</tr>
</tbody>
</table>

Table 3 - Correlations between the six site chronologies (n shown in parentheses).

These series can be easily cross-matched and justifiably combined within a regional chronology. Correlation between the individual site chronologies varies between 0.28 – 0.56 (Pearson's Product Moment Correlation).

(LINDHOLM 1996; LINDHOLM ET ALII 1996). The two chronologies are built from roughly an equal number of samples, although the forest-limit chronology is representative of a much larger region. It is evident that pine growth in these two re-
regions, from the opposite ends of the boreal forest belt, has parallel as well as opposing features. At the end of the 18th and at the beginning of the 19th centuries growth is clearly more pronounced in the south-east than in the north. Around the year 1830, there exists an even more drastic difference in growth lasting several years. Opposing trends in growth appear also around the years 1870 and 1940. Parallel features between the two curves appear during the depression at the turn of the present century as well as during the following increase in growth, culmination during the 1920s.

4.2 Calibrating the climate – tree growth relationship

Growth responses to monthly climate variables

In Fig. 5, the correlation analysis between monthly climate and pine growth shows no consistent patterns. Predictand variables here are the residual chronologies for the six sites. No single climate variable seems to have significant impact on growth at all sites. However, precipitation generally seems to be far more important than temperature. Precipitation during the previous August, and in the concurrent May, June, and July has a po-

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Fig. 4 - A comparison of the chronologies for south-eastern Finland and for the northern forest limit.

Fig. 5 - Correlation functions between climate variables and growth at the six forest stands for the period 1927-1990: Punkaharju (1), Kyroenniemi (2), Eteissaari (3), Sauvasaari (4), Pitkasaari (5), and Huvilasaari (6). Residual chronologies for the six sites were used as predictands. (*) indicates significant (p < 0.05) values for the correlation function analyses.
Table 4 - Correlation coefficients between the regional pine chronology and various intervals of the growing season climate.

<table>
<thead>
<tr>
<th>Interval</th>
<th>Precipitation (r)</th>
<th>A priori significance (p)</th>
<th>Temperature (r)</th>
<th>A priori significance (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>April - June</td>
<td>0.357</td>
<td>0.002</td>
<td>0.042</td>
<td>0.777</td>
</tr>
<tr>
<td>April - July</td>
<td>0.417</td>
<td>0.000</td>
<td>0.073</td>
<td>0.663</td>
</tr>
<tr>
<td>April - August</td>
<td>0.304</td>
<td>0.009</td>
<td>0.075</td>
<td>0.630</td>
</tr>
<tr>
<td>April - September</td>
<td>0.280</td>
<td>0.019</td>
<td>0.145</td>
<td>0.304</td>
</tr>
<tr>
<td>May - June</td>
<td>0.355</td>
<td>0.002</td>
<td>-0.062</td>
<td>0.603</td>
</tr>
<tr>
<td>May - July</td>
<td>0.399</td>
<td>0.001</td>
<td>-0.009</td>
<td>0.845</td>
</tr>
<tr>
<td>May - August</td>
<td>0.267</td>
<td>0.022</td>
<td>0.005</td>
<td>0.923</td>
</tr>
<tr>
<td>May - September</td>
<td>0.233</td>
<td>0.034</td>
<td>0.084</td>
<td>0.554</td>
</tr>
<tr>
<td>June - July</td>
<td>0.332</td>
<td>0.004</td>
<td>-0.051</td>
<td>0.626</td>
</tr>
<tr>
<td>June - August</td>
<td>0.208</td>
<td>0.070</td>
<td>-0.021</td>
<td>0.755</td>
</tr>
<tr>
<td>June - September</td>
<td>0.201</td>
<td>0.088</td>
<td>0.081</td>
<td>0.593</td>
</tr>
</tbody>
</table>

Growth response to seasonal variables

The importance of precipitation as a growth-limiting factor becomes evident when pine growth is calibrated with seasonalized total precipitation and average temperature (Table 4). Correlations between variables of temperature and growth are extremely low. The strongest correlation for total seasonal precipitation is seen for the period April - July and for temperature during April - September. The seasonal correlations are of greater significance than any of those derived using monthly precipitation.

Comparison of growth responses between northern and south-eastern pine

In Fig. 6, growth responses of southern and northern forest-limit pines are compared. In the response function analyses, we have included 14 precipitation and temperature variables (from the previous July to the current August). They are supplemented with three variables representing prior growth years. The two 'standard' regional chronologies were used as the predictand variables.

In both regions, precipitation during previous August and November appear to have a positive and significant impact on growth. In the south-eastern pine, precipitation in January has a negative and in June a positive influence on growth. While temperature in June exerts a significant positive effect in the north, it seems to suppress growth in the south-eastern pines. In addition, temperature of the previous August has a negative influence and during the current May, a positive impact on growth in the south-eastern region.

5. Discussion and conclusions

We have built six site chronologies and a regional master chronology for the central part of the Saimaa Lake district in south-
eastern Finland. In Fennoscandia, the values of the annual ring index series are usually not independent of each other, due to sometimes strong autocorrelation and quasi cyclic variation (Hustich, Elving 1944; Mikola 1950; Henttonen 1984; Briffa et alii 1990; Briffa, Schweingruber 1992; Burroughs 1994; Lindholm 1996). Indeed these features are often considered characteristic of the growth of Scots pine. Their importance increases at high latitudes (Ekholm 1957) and high altitudes (Lamarche 1974). The long needle retention near the tree line has been suggested as an explanation for this phenomenon.

In this analysis of 'southern' boreal tree growth, the chronology statistics indicate that pines exhibit sufficient intra-annual variability and between-sample correlation to allow good crossdating and indicate a significant relationship with climate. Precipitation is, by far, the dominant climatic variable affecting the inter-annual variability of pine growth in this region. The correlation and response function analyses both indicate significant positive effects during the current growing season from May to July. The strength of this relationship increases when precipitation is summed over the April – July interval. Significant positive effects due to high temperatures are also found during the current growing season, viz. May and August. These results indicate that pines will experience increased growth when it is warm and wet.

According to e.g. Laitakari (1920), the width of the annual ring is dependent on the spring temperature of the current year, however, between precipitation and tree growth no correlation could be found. Mikola concludes (1950) that the moisture may exert some influence on diameter growth in Finland, too, but its significance is hard to ascertain because the rainfall and temperature of the growing season are usually more or less inversely proportional. Indeed, when examining tree-ring analyses, it is noticeable that very dry summers have been unfavourable to tree growth on the driest sites, just as very rainy summers on wet peatlands (Mikola 1950). On the other hand Henttonen (1984) states that for the variation of the Scots pine indices the most important climatic factor was the effective temperature sum during the latter part of the growing season and, especially on the arid sites, the precipitation sum during May-July.

The results presented in this paper demonstrate that the variability of critical seasonal climatic variables govern the relative growth rates of pines in southern Fennoscandian forest communities. When compared to studies at the northern forest-limit region, there are greater problems in identifying and separating 'natural' and anthropogenic effects in tree-growth variability in the south. Differentiation between the effects of forestry practices and changing environment requires a priori knowledge of the effect each would have upon tree growth in the absence of the other. In the future, attempts will be made to separate these signals in tree-ring series. A major difficulty in this research will be the presence of a considerable amount of 'background noise'. The development of networks of tree-ring chronologies will help in this work. In addition, non-linear models may need to be tested. Trees being heavily affected by stand dynamics are likely to exhibit changing relationships with the environment over time, even though the environment itself has remained stable (Vandeusen, Koretz 1988).

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LITERATURE


Effects of climate on growth of Scots pine were estimated by correlation and response function analyses. No single climate variable seems to have significant impact on growth at all sites. However, precipitation generally seems to be far more important than temperature. The importance of precipitation as a growth limiting factor becomes evident when pine growth is calibrated with seasonal total precipitation and average temperature. Correlations between variables of temperature and growth are extremely low. The strongest correlation for seasonal total precipitation is seen for the period April - July and for temperature during April - September.

A preliminary comparison was made between chronologies from the northern and southern parts of the boreal zone. It is evident that pine growth in these two regions, from the opposite ends of the boreal forest belt, has parallel as well as contrasting features. At the end of the 18th and at the beginning of the 19th centuries growth is clearly more pronounced in the south-east than in the north. Around the year 1830, there exists an even more dramatic opposition in growth over several years. Opposite trends in growth appear also around the years 1870 and 1940. Parallel features in the two growth curves appear during the depression at the turn of the present century and during the subsequent increase culminating during the 1920s.

RIASSUNTO

Effetti del clima sull'accrescimento del pino silvestre nel distretto del Lago Saimaa, Finlandia sudoccidentale, nella zona meridionale della foresta boreale.

La nota propone un primo tentativo di costruzione di una cronologia anulare e di un modello clima/accrescimento nella regione boreale meridionale.

L'area della ricerca copre la zona circostante la parte centrale del bacino del Lago Saimaa nella Finlandia orientale fra 29°-30° E e 61°-62° N, dove sono stati presi in considerazione 250 esemplari di pino di 10 stazioni diverse. Serie di dati alberi all'interno di sei subaree sono state correlate fra loro e sono state riunite in sei cronologie stazionali.

Le cronologie presentano notevoli affinità che hanno permesso di elaborare una master chronology rappresentativa.

Sono stati esaminati gli effetti del clima sull'accrescimento del pino utilizzando la metodologia delle funzioni risposta. Non risulta che vi sia un fattore specifico con impatto determinante in tutte le stazioni considerate. Tuttavia sembra che le precipitazioni abbiano un'influenza maggiore delle temperature. L'importanza delle precipitazioni come fattore limite appare evidente quando si mette in rapporto l'accrescimento del pino con precipitazioni totali stagionali, mentre le correlazioni temperatura/precipitazioni sono estremamente basse. Le correlazioni precipitazioni stagionali/precipitazioni è particolarmente accentuata nel periodo aprile-luglio; la temperatura esercita una certa influenza nel periodo aprile-settembre. Dal confronto fra cronologie della zona settentrionale e della zona meridionale della regione boreale emergono per il pino analogie e contrasti. Alla fine del secolo 18° e all'inizio del 19° l'accrescimento è più marcati nella zona sud-est che al nord. Intorno al 1830 il contrasto diventa ancora più evidente almeno per alcuni anni; un fenomeno analogo si riscontra negli anni 1870 e 1940.

Andamenti parallelli nelle curve si rilevano durante la depressione all'inizio del secolo attuale e verso il 1920.