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A TREE-RING RECORD OF PAST SUMMER TEMPERATURES IN NORTHERN FINNISH LAPLAND

Abstract

The growth of Scots pine (*Pinus sylvestris*), which forms the coniferous tree limit in Lapland, is known to be a good indicator of past climatic variations.This aids our understanding of how trees respond to climate and allows the reconstruction of past climate. Numerous, well-preserved remains of pine are to be found in lake sediments and peat bogs at and beyond the present forest limit, allowing the construction of a continuous pine chronology for northern Lapland covering 6000 to 7000 years (Eronen et al. 1991, 81–93). This produces quantitative estimates of past climate based on modern climatic variables such as average monthly temperatures. One method of producing quantitative estimates of past climate is based on modern climate variables, such as average monthly temperatures. It is thus possible to reconstruct past climatic conditions well before the period of instrumental weather records.

To make inferences based on the long series of ring width, we started our analysis using living trees in close proximity to an area where modern climate data can be obtained. Forest limit pines were sampled at three sites in Enontekiö area of northern Finnish Lapland.

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Introduction

The ecological consequences of global climatic change have focused growing interest on climatic fluctuations that have occurred throughout the postglacial period (Fritts & Swetnam 1989, 110–118). As instrumental weather records extend back only two or three centuries, knowledge of the climate of pre-instrumental time is still rare. However, there are other means, so-called proxy data such as tree-ring series, that can be used to extend the weather records back in time (Eronen et al. 1991, 81–93).

Long-living trees integrate and record various external growth-controlling environmental influences during their life-time. The life-long record is revealed, and converted into a visible and measurable form, in the width of the annual growth layers, the tree-rings (Fritts 1976, 25–27). Tree-ring series can be considered as a coded year-book.

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In this paper, tree-ring data have been used to reconstruct the mean July temperature for years between AD 1790 and 1900 in northern Finnish Lapland. The present study has been done as part of a research project "Dendrochronology and history of climate in the Fennoscandian subarctic area", which contributes to the SILMU-programme, "The Finnish Research Programme on Climate Change". M. Eronen is leading the subproject.

Climate and tree-ring data

To make inferences based on long ring-width series, the radial growth of living trees was studied

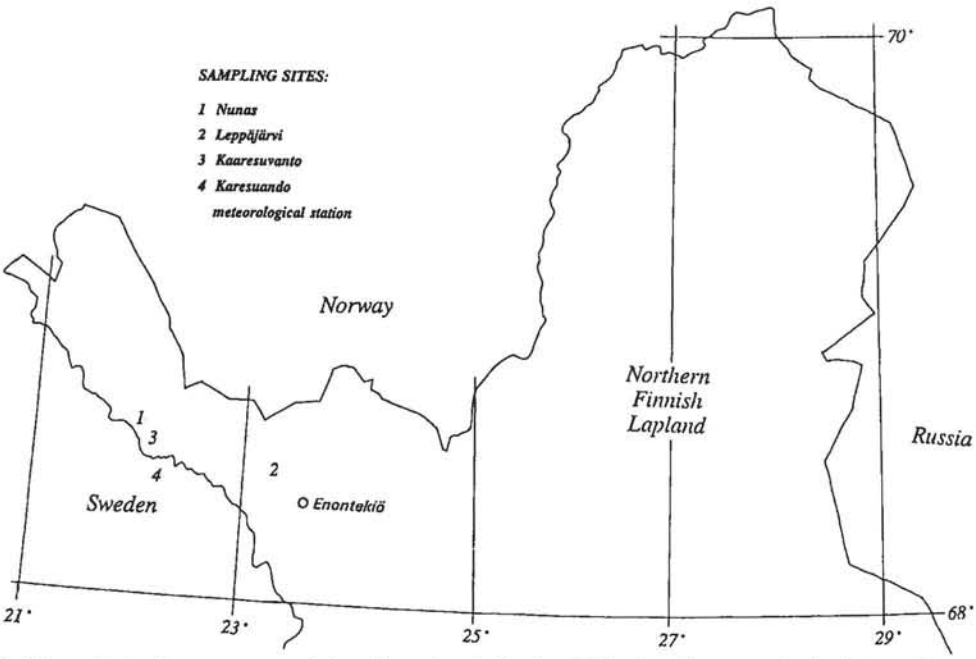

Fig. 1. Forest limit pines were sampled at three sites in Lapland. Weather data was obtained from Karesuando.

in close proximity to an area where modern climate data can be obtained. Forest-limit pines were sampled at three sites of the timberline forest stands in northern Lapland (Fig. 1). Two of the sites at Kaaresuvanto and Nunas are located close to each other in western Enontekiö (68°30'N, 22°00' E, 380 m a.s.l.). The Leppäjärvi site is situated beside the road from Enontekiö to Kautokeino, Norway (68°30'N, 23°20'E, 350 m a.s.l.).

The meteorological station at Karesuando, Sweden, is located in the middle of the Enontekiö sampling area. Continuous records of mean monthly temperatures and precipitation sums are available for comparison with the tree-ring series for the period 1901–1990. This is called the calibration period.

Forest limit pines were sampled using an increment bore. For the study 36 pines were sampled from Kaaresuvanto (J. Meriläinen), 25 and 15 pines from Nunas and Leppäjärvi, respectively (M. Eronen, P. Zetterberg). From these 76 trees 65 were included for further analyses and interpretations performed by M. Lindholm. The tree-ring analyses showed that the growth patterns of the trees were highly consistent, making it easy to correlate all the tree-ring series with each other. A mean chronology was produced for each site (Fig. 2).

Methods

Extracting climatic signal from tree-rings

The climatic signal in tree-ring series of trees growing in the extreme weather conditions at the northern timberline is strong. Trees which have more optimal growing conditions in the south, at less marginal sites, also yield dendroclimatological information, but require more complex methods.

The basic methods in dendroclimatology are standardization, response function analysis, derivation of a transfer function and verification of the results. These methods employ multivariate statistical techniques such as principal component analysis (PCA) and multiple regression (Fritts 1976, 248–376).

Standardization

To eliminate growth changes that are associated with increasing tree age, the tree-ring series were standardized using a low-order polynomial detrending method (Fritts 1976, 261–268).

The three tree-ring chronologies were replaced

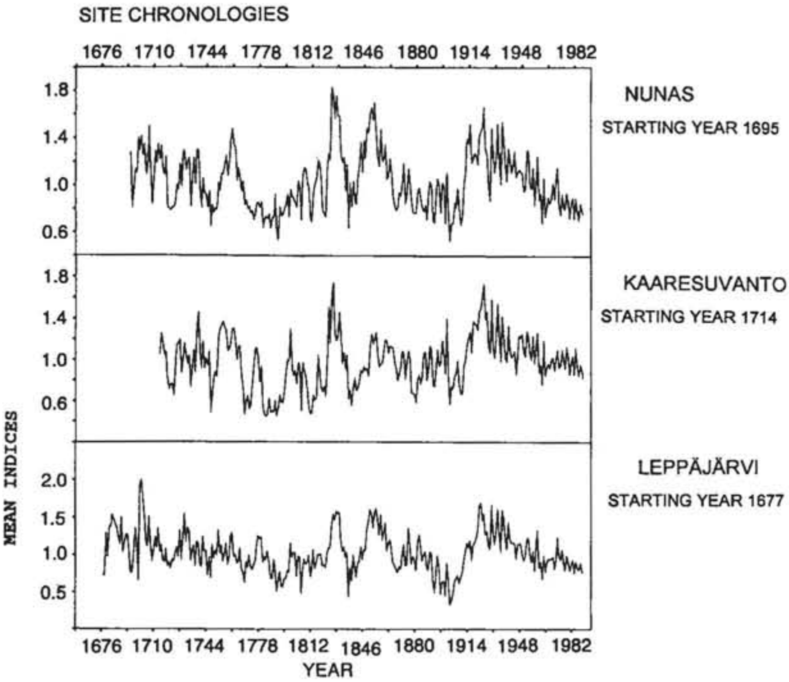

Fig. 2. Site chronologies of Nunas, Kaaresuvanto and Leppäjärvi.

by their principal component time series (Peters et al. 1981, 1–19). These series are linear and orthogonal combinations of the original variables. The principal component series were included in the model on the basis of the amount of predictand variance that they explain and the t-values of their regression coefficients.

Calibration

Response functions are used to evaluate associations between climate variables and ring-width measurements. The direction and relative strength of the climatic forcing on tree growth is expressed in a response function.

Transfer functions are used to calibrate the annual ring measurements with climate variables in order to produce regression equations for climate reconstructions. While the response function is a means of predicting tree performance from climate variables, climate reconstruction requires that climate variables are predicted (reconstructed) from tree-ring variables. As statistical techniques both response and transfer functions measure the effectiveness of a particular model at predicting that part of tree-ring variation believed to be forced by factors external to the forest stand (Hughes & Milsom 1982, 37–38). The biological rationale of our model is that the radial growth of forest limit pine takes place over a few weeks during midsummer. Among the multitude of factors that may affect tree growth, the temperature of the growth season has by far the greatest influence (Aniol & Eckstein 1984, 261–262; Hustich 1948, 1–75; Sirén 1961). Consequently we have tried to reconstruct growth season temperatures.

Results

In order to produce quantitative estimates of past climate based on radial growth of trees, the growth response of trees to different climatic variables must first be determined (Van Deusen 1987, 566–578; 1991, 823–827). Our aim was to define an optimum season for calibration. Mean monthly temperatures and precipitation sums were used as predictors in the models. Fig. 3 shows how trees respond to known climatic conditions. Patterns of growth response in forest-limit pine to climatic effect is derived using multiple regression. Highest values between the ring-width and climatic variations were frequently achieved with the models which included July temperatures. The July temperature coefficient is the largest.

Table 1. Model fitting results for: July mean tmp. Summary of the transfer function statistics.

Independent var.	coefficient	std. error	t-value
Constant	0.00537	0.0313	1.076
Ring-width.PC1	0.22855	0.0220	9.927
Ring-width.PC3	0.61185	0.1539	2.397
R-SQ. (ADJ) = 0.567 SE = 0.3928			

The response function analysis suggests that mean July temperatures may be usefully reconstructed using tree-ring data. The basic method of reconstructing past climate from a number of tree-ring predictors is to derive a multivariable transfer function, which produces estimates of past climate (Briffa et al. 1986, 1–15; 1988, 385–394; 1992, 111–119; Fritts 1976, 376–412). We used a regression model of the form:

$$T_t = b_1 TRW_t + b_2 TRW_{t+1} + b_3 TRW_{t+2}$$

where T_t is the mean July temperature of the forest-limit area in year t; $TRW + TRW_{t+1} + TRW_{t+2}$ are ring-width data in years t, t+1 and t+2 respectively. The regression summary for fitting July temperature on tree-ring data are presented in Table 1. Using the two principal component series of transformed ring-width data as predictors, almost 60% of the variance in July temperatures may be explained with high level of significance.

In Fig. 4 the complete reconstruction from 1790 is plotted as departures from the mean. To avoid the violation of the uniformitarian assumption, we applied the Kalman filter technique to verify that the climate parameters do not vary with time over the 90 year calibration period (Van Deusen 1991, 823–827). The influence of the climatic parameters on tree growth showed no time dependence.

The estimated values were also compared with the actually measured values of the station at Karesuando from 1901 to 1990. During this peri-

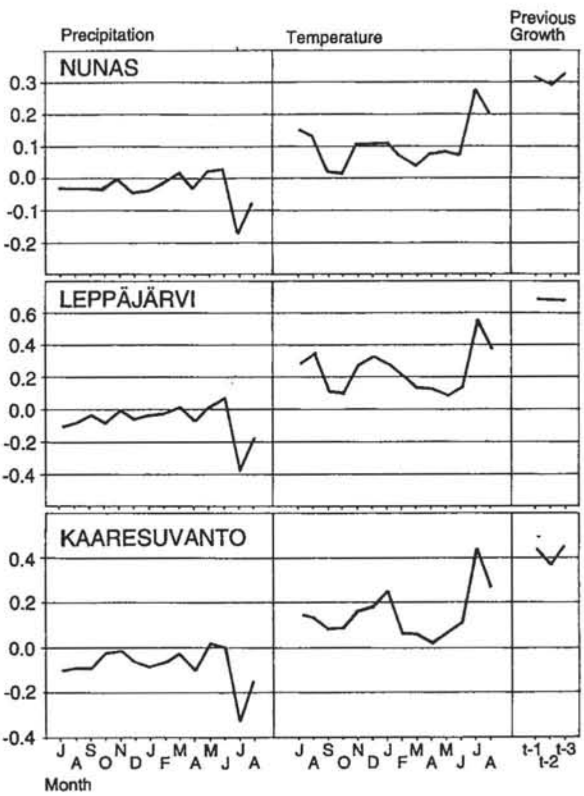

Fig. 3. The growth response in forest-limit pine to climatic forcing of different months. The predictors include 14 monthly temperature and precipitation series for the successive months from July of the year preceding ring formation, through to August of the growing season. Three other variables, ring width for three preceding years are also included.

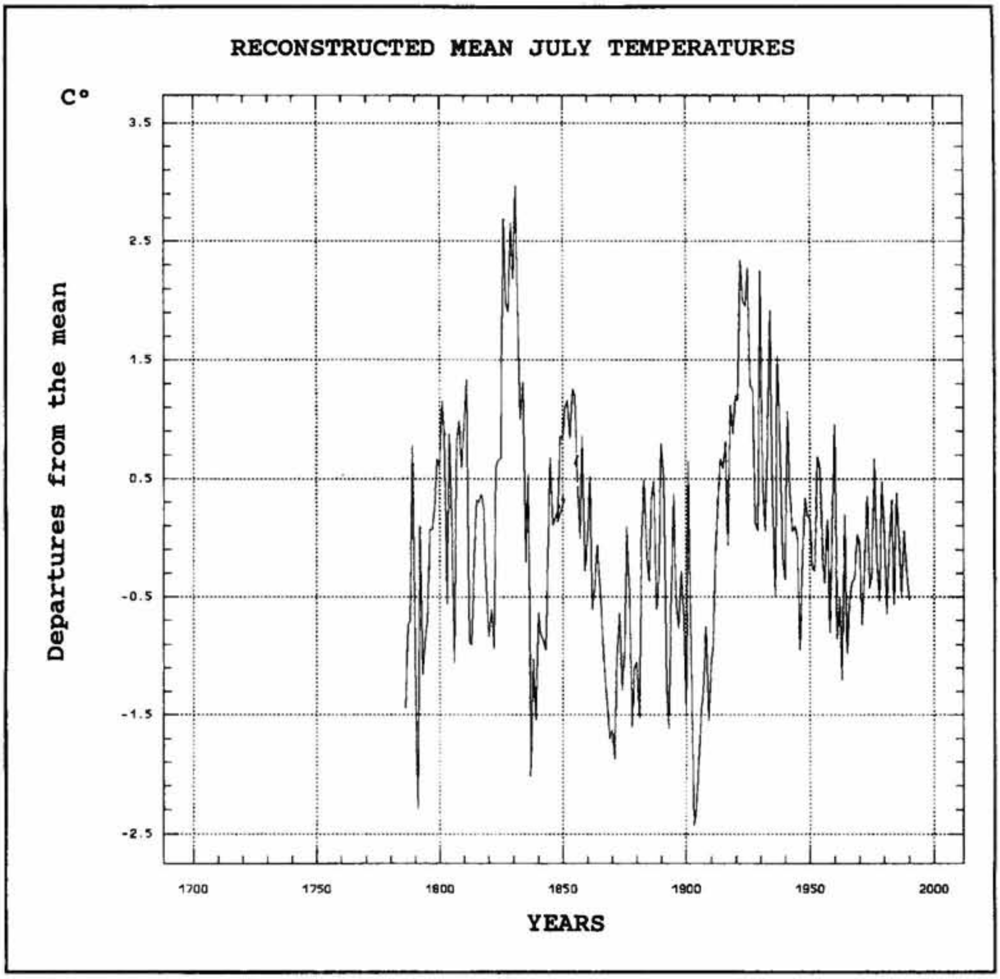

Fig. 4. Reconstructed July temperature as departures from the mean back to 1790 in the forest-limit area. The values for period from 1901 to 1990 are also estimated from tree-rings.

od there is a good similarity between measured and reconstructed temperatures. The predicted versus observed values are presented in Fig. 5. Our reconstruction seems to estimate the cooler periods better. Warm periods from the 1910s to around 1940 are slightly overestimated.

Conclusions

Earlier reconstructions of summer temperatures in northern Fennoscandia show similar trends. These reconstructions have been made at the northern timberline in Sweden (Aniol & Eckstein 1984, 273–279) and over large areas covering parts of Norway and the Kola Peninsula (Briffa et al. 1988, 385–394; 1990, 434–439). They both show a warm period from about 1825 to 1835. Cool periods have prevailed during the 1810's and between 1835–1845. These periods are also evident in our reconstruction.

Paleoclimatic studies need proxy climatic data. When compared with other sources of proxy Holocene data, tree-rings are superior in that they can be assigned to a particular year and they can cover several centuries, even millennia. Tree-ring series will be used increasingly in the future as monitors of environmental and climatic change for the simple reason that they are available where no other comparable long-term sensors exist.

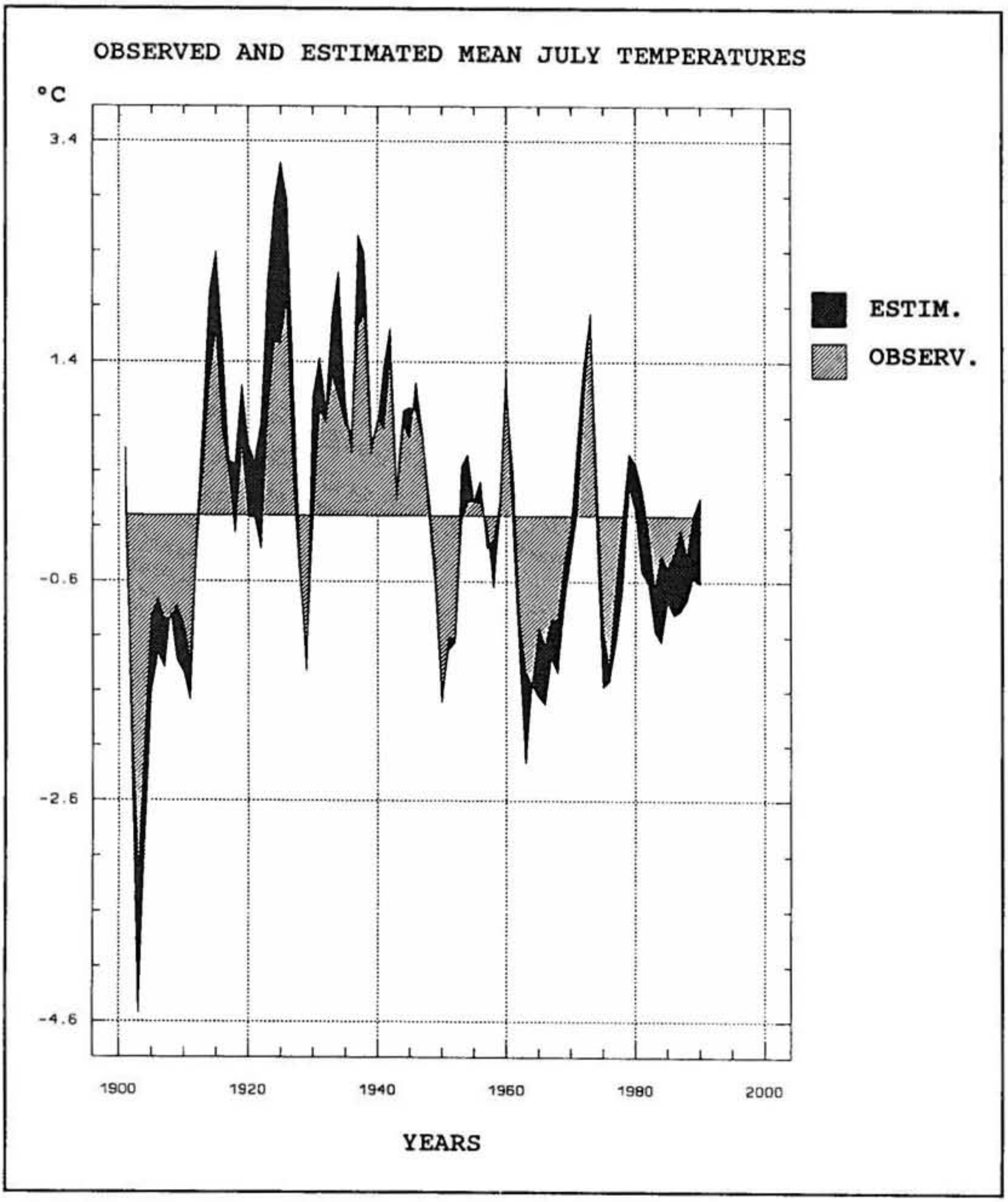

Fig. 5. Estimated (ESTIM.) and observed (OBSERV.) values of July temperatures in normalized units.

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