RECONSTRUCTION OF SUMMER TEMPERATURE FROM TREE RINGS OF SCOTS PINE, *PINUS SYLVESTRIS* L., IN COASTAL NORTHERN NORWAY

Andreas J. Kirchhefer, Department of Biology, University of Tromsø, N-9037 Tromsø, Norway

Abstract: At the coast of northern Norway, 69°N, tree-ring chronologies from Scots pine (*Pinus sylvestris* L.) were constructed at Forfjorddalen in the Vesterålen archipelago (AD 1358-1992), Stonglandseidet on Senja (AD 1548-1994) and Vikran near Tromsø (AD 1700-1992). All chronologies reflect July-August-temperatures. At the northernmost site, Vikran, the response was more confined to July temperature, resulting in a strong tree-ring and climate signal. The chronology from a steep, south-facing slope at Stonglandseidet showed signs of drought sensitivity. At the most oceanic locality, Forfjorddalen, mild winters appear to suppress tree growth on a decadal scale. Growth variations were consistent between the three sites from AD 1700-1910 but the amount of low-frequency variability decreased towards the most oceanic site. The 17th century, the coldest period of the 'Little Ice Age', experienced three cycles of summer temperatures, with minima around AD 1605, 1640 and 1680. An extended warm period occurred around AD 1470-1540. Temperature reconstruction showed secular trends similar to those observed east of the Scandes, but differed in the magnitude and timing of the extremes. At Forfjorddalen, there was no evidence of pine regeneration from around AD 1575-1650. The latter site is likely to have been affected by logging activity in the 17th century.

Key words: Tree-rings, dendroclimatology, *Pinus sylvestris* L., temperature reconstruction, Norway

INTRODUCTION

Analyses of tree rings provide a means to extend back in time the record of climate information at high latitudes. Climate reconstructions have been obtained from circum-polar chronology networks along the northern boreal timberline (D'Arrigo and Jacoby, 1993; Schweingruber and Briffa, 1996). In Fennoscandia, an interest in forest growth and its dependence on climate arose in the early 20th century (Hesselmann, 1904; Wallén, 1917; Kolmodin, 1923; Eide, 1926). Classical dendroclimatological studies north of the Polar Circle include Erlandsson (1936), Hustich (1945) and Sirén (1961). In recent decades, studies on the climate-growth response of Scots pine have been intensified (Lindholm, 1996; Briffa *et al.*, 1998a; 1998b; Kirchhefer, 1998) and efforts have been made to complete continuous multi-millennial chronologies at the northern timberline (Briffa, 1994; Zetterberg *et al.*, 1996). In addition to being influenced by

Arctic conditions, the northern Fennoscandian climate is characterised by heat advection from the Atlantic Ocean. Fennoscandian pine chronologies recently were used in studies on past changes of North Atlantic sea surface temperatures and the North Atlantic Oscillation, NAO (D'Arrigo *et al.*, 1994; Cook *et al.*, 1998).

By comparison, little attention has been paid to the pine forests along the northern Norwegian coast. After the construction of the Steigen-Sørfold chronology (Aandstad, 1939; Ording, 1941), work did not continue until the 1980s, when five chronologies were established north of the Arctic circle (Schweingruber, 1985). In an analysis of spatial variability of tree-ring growth, those chronologies were treated as a dendro-ecological group independent of northern Finland and Sweden. The chronologies subsequently were included in reconstructions of northern Fennoscandian (Briffa *et al.*, 1988a) and western European summer temperatures (Schweingruber *et al.*, 1987; 1991; Briffa *et al.*, 1988b). It is likely that only the chronologies from Steigen-Sørfold and ‘Lofoten’ (Schweingruber, 1985) represent oceanic climate, while the other chronologies are obtained from climatically more continental fjord-heads. Subsequent to the discovery of, at that time, Norway’s oldest pine at another oceanic locality, Forfjorddalen in the Vesterålen Archipelago, three preliminary chronologies were constructed from that site and interpreted in terms of regional climate and its socio-economic implications (Ruden, 1987; Kirchhefer and Vorren, 1995; Thun and Vorren, 1996).

The principal aims of the present study are to contribute to a more complete picture of past and present variation of tree growth and climate in northern Fennoscandia, by addressing a major gap in paleoclimatic knowledge from the northern Norwegian coast. In addition to an extended Forfjorddalen chronology, two new pine chronologies between the Lofoten-Vesterålen archipelago and Tromsø are presented. The dendro-climatic results aim to allow regional comparisons with northern Sweden (Briffa *et al.*, 1992) and northern Finland (Lindholm, 1996). It is hoped that the present results will be used to supplement existing chronologies from northern Fennoscandia in larger-scale climate reconstructions.

THE STUDY AREA

Close to the coast of Lofoten-Vesterålen and Troms, northern Norway, mountains rise straight from the sea to elevations of 500-1000 m a.s.l. These act as barriers against cool-moist Atlantic air masses, and up to 2500 mm precipitation per year is retained in

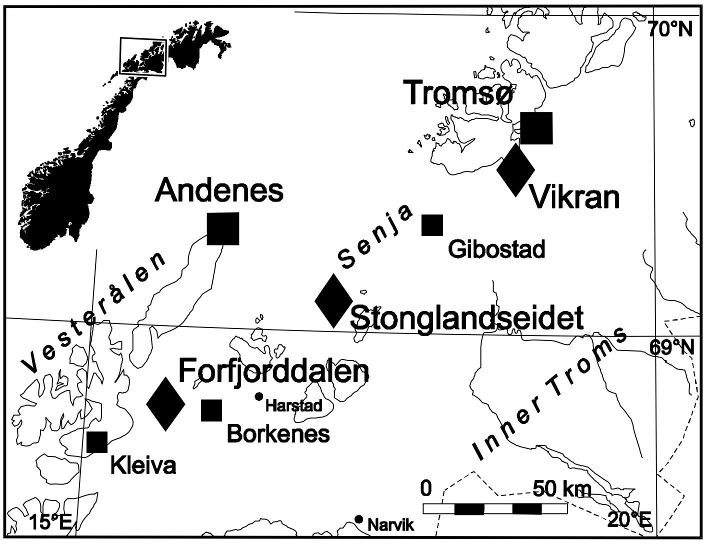

Figure 1: Map of the study area, showing the positions of the investigated sites (♦) and climate stations (■).

the alpine areas of the Lofoten-Vesterålen Archipelago. The coastal pine forests are thought to receive about 1000 mm annual precipitation, while the precipitation regime still is oceanic, with a May minimum and an October maximum (Førland, 1993). As a result of heat advection from the North Atlantic, mean July and August temperatures at the outer coast of Vesterålen and Senja (69°N) during 1961-1990 are 11°C (Aune, 1993). Temperatures near the pine forest localities in the inner part of the archipelago generally reach 12.0-12.5°C at sea level (Figure 1, Table 1). Reflecting the gradient of continentality from Andenes to Tromsø, the annual temperature amplitude is smaller and the extremes occur later at Andenes (Table 1). The westernmost isolated forests of Scots pine (*Pinus sylvestris* L.) occur at 30 km distance from the outer coastline. These forests belong to the middle boreal zone (Moen, 1998). In these areas, Scots pine dominates the canopy where soils are poor and dry, or on mire margins. Many forests are undisturbed by man, and Scots pine often reaches ages of 500 years.

Table 1: Climate parameters for selected months during the normal period 1961-1990, including the temperature difference between the warmest and coldest month (Δ) and the annual precipitation. The positions of the climate stations are given in Figure 1.

	latitude, longitude	m a.s.l.	temperature (°C)					precipitation (mm)				
			July	Aug.	Jan.	Feb.	Δ	May	July	Aug.	Oct.	annual
Andenes	69°18'N, 16°09'E	10	11.0	11.0	-2.1	-2.2	13.2	53	67	77	144	1060
Kleiva	68°39'N, 15°17'E	23	12.5	12.2	-2.1	-1.9	14.6	65	80	89	205	1397
Borkenes	68°46'N, 16°11'E	36	12.6	12.1	-2.8	-2.5	15.4	33	51	56	109	820
Gibostad	69°21'N, 18°04'E	12	12.3	11.6	-4.4	-4.2	16.7	39	62	71	119	900
Tromsø	69°39'N, 18°56'E	100	11.8	10.8	-4.4	-4.2	16.2	48	77	82	131	1031

Table 2: Site characteristics for Vikran (VIK), Stonglandseidet (STO) and Forfjorddalen (FF2): geographical position, elevation, slope aspect and inclination, sampling area and substrate.

	latitude, longitude	m a.s.l.	slope	sampling area	substrate
VIK	69°32'N, 18°44'E	80-120	5° NE	1.5km×0.5km	glacial till between mires
STO	69°05'N, 17°13'E	80-210	25° S	0.5km×0.2km	bare rock, thin cover of glacial till
FF2	68°48'N, 15°44'E	50-170	15° W	1.0km×0.2km	moraine, glacifluvial sediments, talus slope

MATERIAL AND METHODS

CHRONOLOGY BUILDING

Standard techniques were applied for sampling and chronology construction (Fritts, 1976; Cook and Kairiukstis, 1990). Two cores were taken from at least 20 dominant living Scots pines (*Pinus sylvestris*) in open-canopy stands close to the timberline. Samples from dead trees, snags, logs and stumps were collected in order to prolong the tree-ring records. The trees were selected at the driest sites available at each locality. The core surface was cut with a razor blade and polished with white chalk. Tree-ring widths were measured with a resolution of 0.001mm. In order to detect measuring errors and missing rings, the series of each radius, each tree and the mean curve were compared, i.e. cross-dated, by visually examining the cores and tree-ring curves. This process was assisted by correlation analysis (COFECHA; Holmes *et al.*, 1986). Dead wood was dated by the same means.

In order to reduce statistical noise in the chronologies and to enhance the climate signal and long-term trends, sequences containing compression wood were excluded from further analysis. Also periods of reduced growth at the beginning or end of the series were rejected. If major breaks in growth rates occurred in the middle of long series, these were split and subsequently treated as two separate series. Series shorter than ~100 years were discarded. Frequently, samples do not contain the innermost rings of the stem because of wood decay or imperfect coring. If the distance between the innermost present ring and the pith could be estimated realistically from a concentric ring pattern on the core, the number of lacking rings was deduced from the width of the innermost present rings. Knowledge of the cambial age of the tree rings assists tree-ring standardisation and improves the estimation of the tree age and population structure.

When computing the mean growth trend of all radii, it became obvious that fitting negative exponential functions would be the most appropriate way of tree-ring standardisation. Thereby, the age-related growth trend was removed, while a portion of the low-frequency variation and positive growth trends were preserved. In some cases, e.g., samples lacking a large number of innermost rings, horizontal or negative-sloping straight lines were fitted. All chronologies were computed applying bi-weight robust means. For analysis of climate-growth response, RESIDUAL chronologies were constructed after removing autocorrelation from the individual series. Finally, for climate reconstruction, ARSTAN chronologies were produced by reintroducing the pooled auto-correlation into the whitened radius-series before computing the chronologies. ARSTAN chronologies are homogeneous regarding autocorrelation and contain a maximum of low-frequency variability, and therefore are better suited for climate reconstruction than STANDARD chronologies (Cook, 1985; Holmes *et al.*, 1986; Lindholm, 1996). The expressed population signal (EPS), i.e. the number of trees required to satisfactory represent the pine population, was used to define the reliable part of the chronologies (EPS ≥85%; Wigley *et al.*, 1984; Briffa and Jones, 1990).

DENDROCLIMATIC ANALYSIS

Mean monthly temperatures were available from the meteorological stations Tromsø and Andenes back to 1868, and precipitation data back to 1868 and 1911, respectively. The Tromsø data was derived from the homogeneity tested and corrected North Atlantic Climatic Data Set, NACD (Frich *et al.*, 1996). The Andenes record shows an inhomogeneity in the year 1963 due to a relocation of the station. Visual comparison with several neighbouring stations revealed other possible inhomogeneities in the Andenes temperature series in the 1890s, 1914/15 and 1971/72. No corrections were undertaken, as they represent temperature changes far less than the year-to-year variability, and might partly reflect spatio-temporal changes in climate.

Climate-growth response was examined for the sub-periods 1875-1914, 1916-62 and 1964-92, as well as for the main period 1916-1992 and at Vikran 1875-1992. The Vikran chronologies were related to Tromsø climate, and the Stonglandseidet and Forfjorddalen chronologies to Andenes climate. RESIDUAL chronologies were compared with the climate of the previous September through the current August by bootstrap orthogonal regression (PPPbase; Till and Guiot, 1990; Guiot and Goeury, 1996). In the analyses of the ARSTAN chronologies, prior ring widths were added as explanatory variables. The procedure includes principal component analysis (PCA), thereby reducing the number of, and circumventing multi-collinearity between, the explanatory variables. Principal components were chosen by the PVP criterion (Guiot, 1985). The bootstrap routine (Efron, 1979) stabilises the regression results by repeating the analyses on a large number of subsamples of the original data set. In this study, 1000 iterations were performed. The ratio (>2) between mean correlation coefficients from the individual analyses and its standard deviations were used as a guideline for the significance of calibration and verification multiple correlation coefficients, as well as for the regression coefficients. The 90% confidence limit for the regression coefficients were derived from the 5th and 95th percentiles.

In order to determine to which extent autocorrelation has to be considered in the transfer functions, all-subsets multiple regression was performed on July-August mean temperatures as dependent variables and the ring widths of the ARSTAN chronologies as explanatory variables, including one leading ring (t-1) and three lagging rings (t+1 to t+3). Transfer functions were computed by bootstrapped orthogonal regression.

RESULTS AND DISCUSSION

AGE STRUCTURE, FOREST CONTINUITY AND CLIMATE

Tree ages increased towards the south-west of the sampling area (Figure 2, Table 3). The maximum age of Scots pine at Vikran generally did not exceed 400 years, but four individuals were determined to be 600 years old at Stonglandseidet. At Forfjorddalen, a new maximum age for Scots pine in Norway was recorded. The innermost ring extracted from a living pine at 40 cm above ground was dated to AD 1228. Adjusted for sampling height and another 10-15 rings between core and the pith, the age of the tree in 1995 was estimated to be at least 790 years. Also the tree-ring measurements of the former Norwegian ‘record holder’ (705 years, AD 1275-1979) were included in the Forfjorddalen chronology. The observed tree ages might imply that climate fluctuations have been less severe in the south-western, most oceanic part of the study area. In contrast to Vikran, abundant tree remains were available at Stonglandseidet and Forfjorddalen (Figure 2). Wood remains from the latter site are significantly older and contain longer tree-ring sequences than those from Stonglandseidet. Unlike tree age, the presence of dead wood and the number of rings preserved in it are more dependent on soil and air humidity as well as human activity and thus cannot readily be interpreted in terms of climate variability.

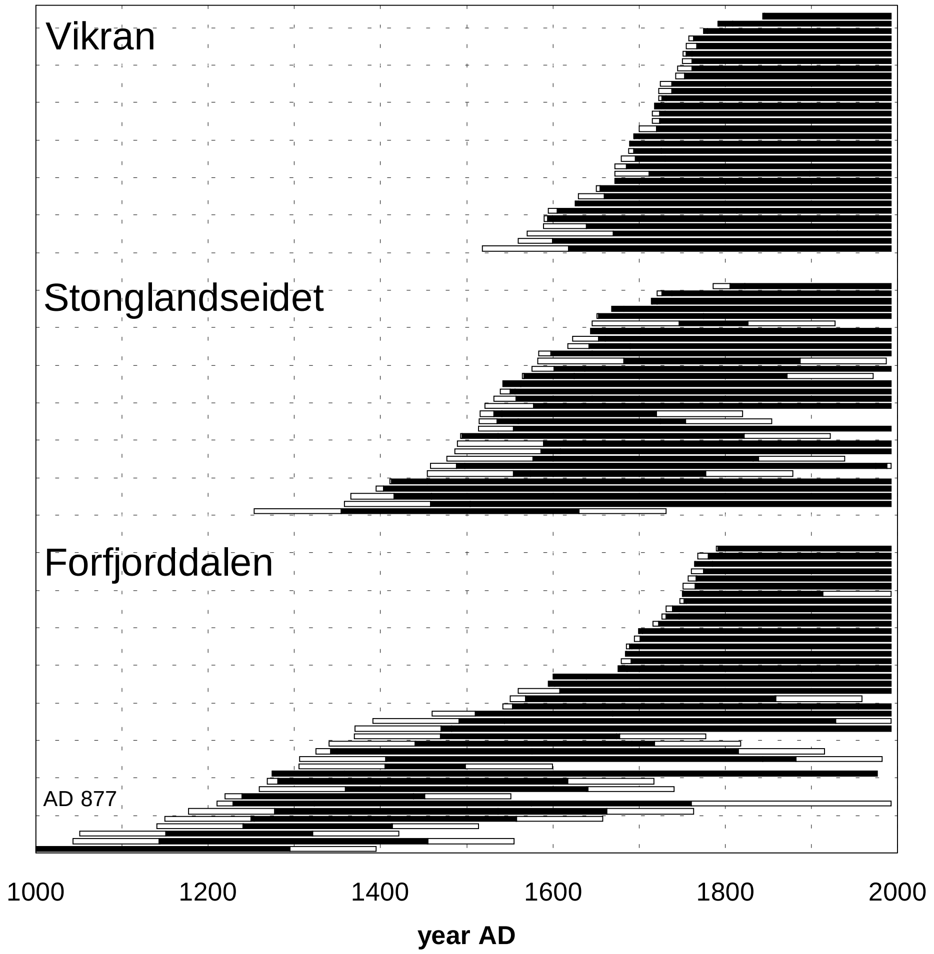

Figure 2: The life span of the trees (bars) sampled between 50 and 100 cm above ground, an estimate of the age structure of the dominant tree layer. Black: sampled rings; white: estimated rings (pith missed, decay, erosion; where no realistic estimate was possible, 100 rings were added).

At Stonglandseidet and Vikran, pine recruitment appears to be relatively even during the observed period, i.e. AD 1300-1700 and 1500-1800, respectively (Figure 2). However, at Forfjorddalen, there is strong evidence for a gap in pine recruitment between AD 1600 and 1675; i.e. ~ AD 1575-1650, when corrected for sampling height. Corresponding gaps are observed in inner Troms (Kirchhefer *in prep.*), northern Sweden (Kullman, 1996) and northern Finland (Sirén, 1961). Also at Forfjorddalen, few pines seem to originate from the years AD 1400-1570, while during the same period at Stonglandseidet, there was strong pine regeneration. This suggests logging activity, because Forfjorddalen is the only local source of timber in Vesterålen and was presumably important during the expansion phase of human settlements after the abandonment of farms during AD 1350-1500. Documents from the 17th century report that Forfjorddalen provided pine logs for construction of the church at Hadsel in AD 1639, and most likely also for the church at

Sortland AD 1675 (Guttormsen, 1990). Extensive logging of pine aged around 150 years would cause such a phenomenon.

Table 3: Chronology characteristics for Vikran (VIK), Stonglandseidet (STO) and Forfjord-dalen (FF2): mean sensitivity (MS), standard deviation (SD), first order autocorrelation (r_{AR1}), variance due to autoregression (VAR_{AR}), the autoregressive model (AR n), correlation between trees (r_{TRE}), correlation between radii and chronology (r_{RM}), signal-to-noise ratio (SNR), expressed population ratio (EPS), and variance explained by the first principal component (VAR_{PC1}) (Holmes *et al.*, 1986). The common time period was set to AD 1785-1987 for all chronologies.

		FF2	STO	VIK
total time span AD		877-1994	1403-1997	1599-1992
n trees (radii)		36 (71)	29 (55)	23 (44)
mean series length (yr)		264	257	246
min./max. series length (yr)		119 / 543	94 / 539	95 / 394
ring-width median (mm)		.49	.42	.51
STANDARD chron.:	MS	.189	.169	.171
	SD	.248	.229	.255
	r_{AR1}	.533	.580	.678
	VAR_{AR}	28.2 %	38.5 %	50.9 %
RESIDUAL chron.:	AR model	AR 3	AR 3	AR 5
	MS	.205	.189	.194
	SD	.181	.163	.173
ARSTAN chron.:	MS	.188	.167	.166
	SD	.265	.234	.239
	r_{AR1}	.602	.612	.641
	VAR_{AR}	27.0 %	44.5 %	46.5 %
AD 1785-1987	n	18 (33)	17 (26)	18 (32)
detrended series:	r_{TRE}	.400	.406	.422
	r_{RM}	.647	.648	.665
	SNR	12.0	11.6	13.1
	EPS	.923	.921	.929
	VAR_{PC1}	43.0 %	45.0 %	45.6 %
	SD	.239	.243	.253
	EPS 85% since AD	1358	1548	1700
	EPS 90% since AD	1692	1563	1730
	n trees EPS 85 (90)%	9 (14)	9 (14)	8 (13)
RESIDUAL series:	r_{TRE}	.495	.434	.482
	r_{RM}	.708	.664	.690
	SNR	17.7	13.0	16.8
	EPS	.946	.929	.944
	VAR_{PC1}	52.0 %	46.3 %	50.4 %
	SD	.196	.173	.175

CHRONOLOGY CHARACTERISTICS

In accordance with the occurrence of old trees and tree remains, the longest chronology was obtained from Forfjorddalen, with one sample dating back to AD 877 (Figure 2). Both at that site and at Stonglandseidet, tree-ring series from nine trees were required for a chronology reliable at 85% expressed population signal (EPS; Table 3). The more homogeneous Vikran material required only eight trees. Assuming homogeneous statistical properties over the entire chronologies, the well-replicated series extended back to AD 1700 at Vikran, AD 1548 at Stonglandseidet, and AD 1358 at Forfjorddalen. Only these parts are presented (Figure 3), because the amplitude of the earlier, less-replicated tree-ring sequences are higher and carry the risk of misinterpretation. Due to relatively low replication in its first half, the Forfjorddalen chronology did not reach 90% EPS until 1692 (n = 14 trees; Figure 3).

The shortest series, Vikran, is the most homogeneous, with the highest correlation between trees, signal-to-noise ratio, EPS and variance in the first eigenvector (Table 3). The high amount of low-frequency variability in the Vikran chronology was expressed by the strong autocorrelation statistics. In contrast, the Forfjorddalen chronology contained the most year-to-year variability, as indicated by mean sensitivity.

The mean correlation between the STANDARD chronologies was r = 0.63 for AD 1700-1992, with the maximum value between Stonglandseidet and Vikran (r = 0.70); the mean Gleichläufigkeit, Glk (Eckstein and Bauch, 1969), AD 1700-1992 was 80.2%. The highest value was found between Forfjorddalen and Stonglandseidet (82.0%) and the lowest between Forfjorddalen and Vikran (77.7%). The figures were higher than those reported by Schweingruber (1985) for a group of three chronologies from northern Norway (Glk = 68.8%), and indicate a high climatic homogeneity of the study area, with a common dominant growth-limiting factor.

GROWTH VARIATIONS

All chronologies show above-average growth during major parts of the 20th century after 1910 (Figure 3), though there was more between-site variation than in earlier centuries. Maximum growth at Forfjorddalen and Vikran occurred during the period 1910-55. Stonglandseidet reached maximum growth somewhat later, between 1940-92. Comparably high growth rates also occurred during the 10 years from AD 1793 to 1802, and during a long, stable period AD 1475-1540. The year 1985 is conspicuous with the broadest ring since AD 1535.

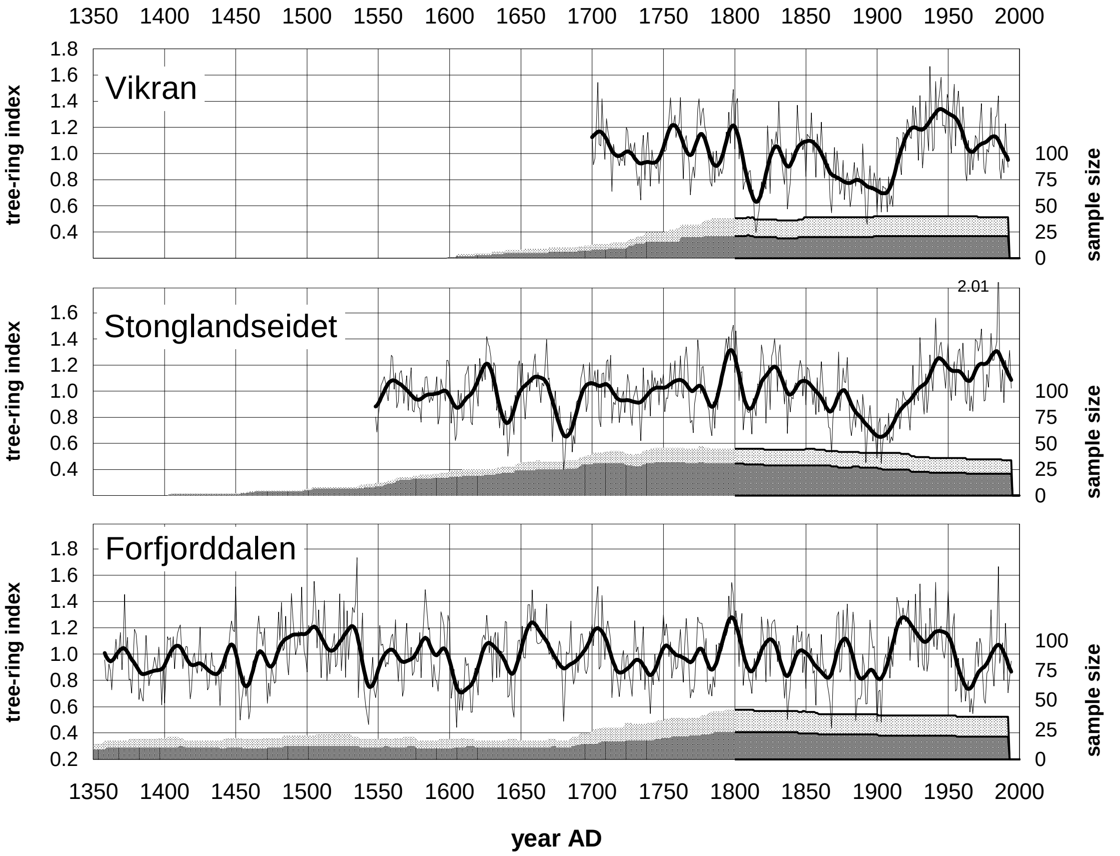

Figure 3: The STANDARD chronologies. Only those sequences comprising a minimum of eight (Vikran) or nine trees (Forfjorddalen, Stonglandseidet) are shown, thus expressing more than 85% of the population signal (EPS). The number of radii and trees included in the chronology are displayed below the chronologies. The low-frequency tree-ring variability is represented by a cubic smoothing spline with a cut-off level at 50% variability per 20 years (bold line).

In contrast to the high growth rates seen from the 1920s, during the years 1881-1910, all sites suffered from heavy growth depressions. At Vikran, growth already declined in the late 1860s, and here poor growth occurred also between AD 1805-1820. Before the relatively stable 18th century, growth depressions occurred in the AD 1450s, the 1540s and 1601-1620 in Forfjorddalen. The Stonglandseidet chronology displayed additional negative anomalies around AD 1640 and 1680. Kirchhefer and Vorren (1995) observed a lower level of tree-ring indices during the second half of the 17th century in Forfjorddalen. That chronology consisted of nine trees dated back to at least AD 1500, but included solitary-growing pines from the damp, east-facing slope. Thus the positive growth trend in the present chronology is considered to be a site-specific signal, related to site-specific climate response, age distribution of the sample trees, or the proposed disturbance logging activity.

In agreement to the long-term variability in growth rates, the narrowest tree rings occur in the 17th and 19th centuries and in the AD 1450s and 1540s (1453/59/60, 1542/43, 1605, 1641, 1680, 1837, 1868, 1892/93, 1900/03). The ten broadest rings occurred around AD 1500 (1450, 1489, 1496, 1505, 1523, 1535), in 1799 and in the 20th century (1930, 1941, 1985).

CLIMATE-GROWTH RESPONSE OF SCOTS PINE

In the present study, the most significant growth-limiting factor was July temperature (Tables 4 and 5). At Stonglandseidet and Forfjorddalen, the sensitive period was longer, and temperatures in August were also found to influence growth considerably. July precipitation was negatively correlated with growth at Vikran and Forfjorddalen, most likely due to reduced insolation and, especially at Vikran, soil cooling. The positive response to May precipitation is best interpreted as rain causing early snow-melt and soil-warming, thus enabling an early start of the vegetation period. Such precipitation effects were not seen at Stonglandseidet. This locality has a low water capacity and is likely to profit from moisture supply from late-melting snow and rainfall during June through August, while the steep south-facing slope gives relatively high temperatures.

RESIDUAL and ARSTAN chronologies displayed similar climate responses. When applying the ARSTAN versions of the Forfjorddalen and Vikran chronologies, ring widths of the lagging rings (t+1), (t+3) and (t+4) were significantly positively correlated with radial growth of the current year. At Stonglandseidet, only the rings (t+1) and (t+2) were significantly positively correlated. The length of the calibration period had a profound effect on the stability of the response functions. The shortest period, 1964-1992 (29 years), was considerably over-calibrated, as shown in the non-significance of the verification coefficients (Table 4). By extending the calibration period, the coefficients for calibration and verification approach each other and stabilise.

Previously, a predominant response to July-August temperatures was found in Forfjorddalen (Kirchhefer and Vorren, 1995; Thun and Vorren, 1996), and at Torneträsk at the eastern slope of the Scandes (Briffa *et al.*, 1990; 1992). In contrast, a short season affecting radial growth, comprising July only, is reported from inner Troms (Thun and Vorren, 1996), in earlier studies at Lake Torneträsk (Erlandsson, 1936; Bartholin and Karlén, 1983; Aniol and Eckstein, 1984; Eckstein *et al.*, 1991), and in northern Finland(Hustich and Elfving, 1944; Briffa *et al.*, 1988a). In a recent investigation, the growth response was mainly related to June-July temperatures in eight out of nine northern Finnish pine chronologies (Lindholm, 1996). These results imply that the

Table 4: Response functions based on bootstrap orthogonal regression on RESIDUAL chronologies and monthly climate data from previous September to current August. Mean bootstrap multiple correlation coefficients (×100) and their standard deviations (×100) are shown for the calibration (cal) and verification procedure (ver) (Till and Guiot, 1990). When significant at the 90% confidence level, mean bootstrap regression coefficients (plain text) and the ratio mean:standard deviation (italics) are shown for individual months. The last three columns (r temp.) show the simple correlation coefficients between tree-rings and July, August and mean July-August (JA) temperatures. Missing data is shown as (-).

	mean r		temperature								precipitation										r temp.		
	cal	ver	Sep	Oct	Dec	Jan	Mar	Jun	Jul	Aug	Sep	Oct	Dec	Jan	Feb	Mar	Apr	May	Jul	Aug	Jul	Aug	JA
VIK																							
1964 -1992	96 *±3*	25 *±28*				22 *1.9*			39 *3.2*											22 *1.6*	56	37	57
1916 -1962	89 *±4*	46 *±18*					22 *2.0*		21 *2.5*		-18 *-1.8*		26 *2.3*					20 *2.1*	-23 *-2.4*		52	36	53
1875 -1914	91 *±4*	40 *±18*			34 *3.2*			22 *2.0*		18 *1.9*						-25 *-2.4*	20 *1.9*		-18 *-1.8*		41	34	49
1916 -1992	79 *±5*	44 *±13*		-18 *-2.1*					31 *4.1*		-14 *-1.8*		17 *2.0*					20 *2.4*	-22 *-2.9*		54	35	54
1875 -1992	74 *±4*	50 *±10*		-11 *-1.8*					29 *4.3*		-11 *-2.0*	-15 *-1.9*						20 *3.6*	-20 *-3.2*		54	37	55
STO																							
1964 -1992	95 *±4*	20 *±30*							30 *2.0*												55	46	58
1916 -1962	83 *±5*	24 *±20*	-22 *-2.0*						20 *1.7*	17 *2.0*											39	41	45
1916 -1992	74 *±5*	33 *±16*							31 *4.2*	23 *3.0*		-17 *-1.8*			-15 *-1.7*					26 *2.8*	45	39	48
1875 -1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	48	41	51
FF2																							
1964 -1992	95 *±5*	8 *±29*												-33 *-2.0*							51	48	57
1916 -1962	85 *±5*	29 *±20*							34 *3.1*	23 *2.7*								28 *2.3*	-23 *-2.0*		55	48	58
1916 -1992	77 *±4*	42 *±13*							36 *4.7*	22 *2.7*		-20 *-2.1*						21 *2.5*	-16 *-1.8*	18 *2.1*	53	47	57
1875 -1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	49	46	55

western chronologies reflect a later and broader time-window (July-August) than the eastern chronologies (July, June-July). However, the dendroclimatological investigations in northern Fennoscandia cannot be directly compared, because they are based on different time periods and statistical techniques. These effects are demonstrated in the present study (Tables 4 and 5).

Table 5: Response functions for the ARSTAN chronologies. The functions include four prior rings as explanatory variables. For further explanations see Table 4.

	mean r		temperature				precipitation				prior rings				r temperature		
	cal	ver	Dec	Apr	Jul	Aug	May	Jun	Jul	Aug	t-1	t-2	t-3	t-4	Jul	Aug	JA
VIK																	
1920-1992	84	54	12	16	28				-24		14		13	18	58	32	54
	±4	*±13*	*1.8*	*2.2*	*4.4*				*-3.3*		*2.2*		*1.8*	*2.3*			
1879-1992	89	76			27	10	13		-11		21		11	25	60	35	58
	±2	*±7*			*5.6*	*1.8*	*3.8*		*-2.4*		*5.8*		*2.4*	*4.7*			
STO																	
1920-1992	81	51	18		27	19		12		22	33	12			41	25	37
	±4	*±13*	*2.0*		*3.4*	*2.7*		*1.6*		*2.2*	*4.9*	*1.6*					
1879-1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51	40	53
FF2																	
1920-1992	84	53		12	28	18	18		-16		28		17	14	47	39	49
	±4	*±14*		*1.7*	*3.2*	*2.6*	*2.3*		*-1.8*		*3.2*		*2.3*	*2.4*			
1879-1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-	47	41	51

CALIBRATION OF TRANSFER FUNCTIONS

Based on the response-function analyses, July-August temperatures were selected for climate reconstruction. Transfer functions were computed which explained July-August mean temperatures by ring-width indices. Mean bootstrapped correlation coefficients were obtained of r = 0.71 to r = 0.60 for the calibration procedure (Table 6). At Stonglandseidet, the function includes four tree rings (t, t+1, t+2, t+3). At Vikran, the first lagged ring (t+1) was not significant, and the model thus contains the rings (t), (t+2) and (t+3). At Forfjorddalen, the model (t-1, t, t+1) proved superior over other alternative models. In all cases, negative weights were assigned to the prior (t-1) and the lagging rings (t+1) and (t+2), while positive weights to the third lag (t+3). Thus, the Forfjorddalen model (t-1, t, t+1) works as a high-pass filter. Therefore an alternative model FF2 (t, t+1,t+2) accounting for more low-frequency variability was chosen (Table 6). All models contain more lags than the transfer functions (t, t+1) which were applied in previous northern Fennoscandian studies (Briffa *et al.*, 1988a; 1992; Lindholm, 1996).

The temperatures reconstructed from the Vikran-chronology closely followed the decadal trend of the instrumental record (Figure 4). This is at least partially attributed to the high quality instrumental climate record at Tromsø, the short distance between climate station and pine locality and a short, well-defined growing season due to the north-facing slope. The strength of the models and amount of the expressed temperature amplitude decreased from Vikran to Forfjorddalen (Figures 4 and 5, Table 6). For the time interval AD 1700-1989, the standard deviation of the annual reconstructed

Table 6: Calibration and verification statistics for the temperature reconstructions 1875-1989: mean bootstrap correlation coefficient (mean r) and standard deviations (SD) for the calibration (cal) and the verification procedure (ver), explained variance adjusted for degrees of freedom (R^2_{adj}), product-mean test (t), sign test (sign), and number of negative sign-products of the first differences (diff.) (Fritts, 1976). For the low-frequency variability (10-year low-pass filter), simple correlation coefficients (r), R^2_{adj}, the results of the product-mean test and the ratio between the observed and estimated standard deviations are indicated (ratio_{SD}).

		mean r ± SD		reconstruction				low frequency			
		cal	ver	R^2_{adj}	t	sign	diff.	r	R^2_{adj}	t	ratio_{SD}
VIK	(t,t+2,t+3)	.71 ± .04	.69 ± .08	.49	5.8	43	38	.91	.82	11.9	1.07
STO	(t,t+1,t+2,t+3)	.60 ± .04	.56 ± .09	.33	5.4	32	32	.77	.58	8.5	1.30
FF2	(t-1,t,t+1)	.60 ± .04	.56 ± .10	.34	5.3	36	30	.23	.03	2.8	3.09
FF2	(t,t+1,t+2)	.56 ± .05	.50 ± .11	.29	5.2	40	30	.28	.05	3.8	2.39

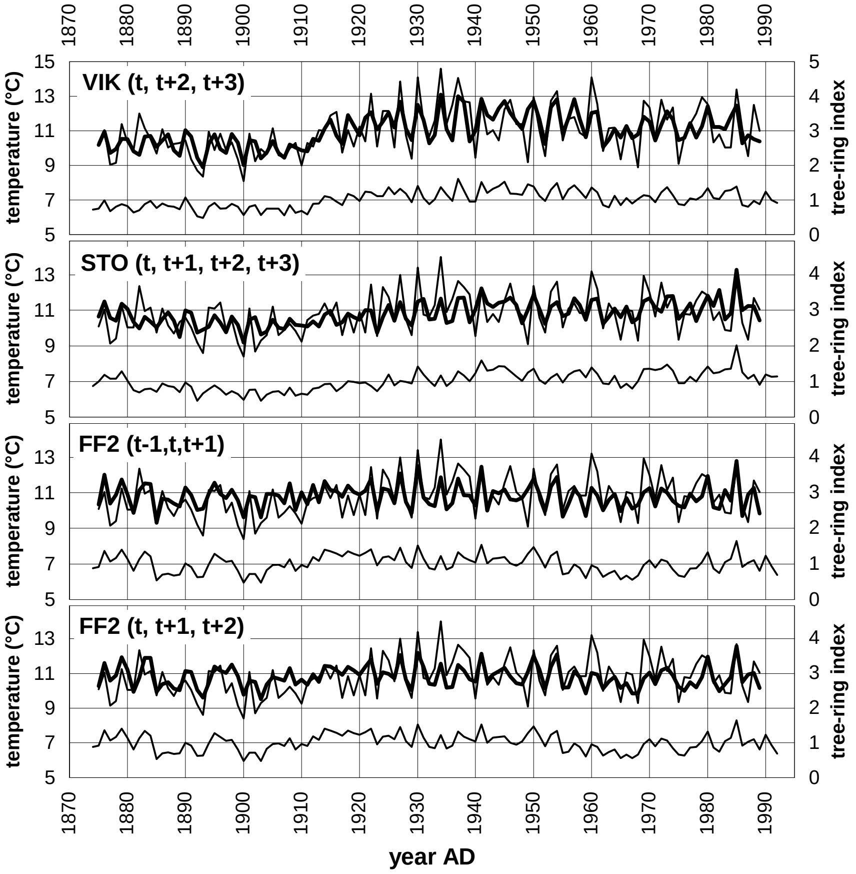

Figure 4: Visual comparison of the ARSTAN tree-ring series (thin, lower), observed (thin, upper) and reconstructed July-August-temperatures (bold, upper), AD 1874-1992. The Vikran chronology (VIK) is compared with the Tromsø climate series, the chronologies from Stonglandseidet (STO) and Forfjorddalen (FF2) with Andenes climate.

temperatures ranged from 0.90°C at Vikran to 0.56°C at Forfjorddalen (t, t+1, t+2). The amplitudes of the low-pass filtered series is highest at Vikran (2.31°C), while only reaching a maximum of 0.9°C at Forfjorddalen (model t, t+1, t+2).

Part of the trend in the amount of expressed low-frequency variability may be due to a more oceanic climate at the south-western sites. The standard deviation of July-August temperatures between 1875-1989 at Tromsø was 1.4°C and the amplitude 6.5°C, while the corresponding values for Andenes are 1.1°C and 5.6°C (Figure 4). Because the Forfjorddalen and Stonglandseidet chronologies were both related to Andenes climate, these two reconstructions are expected to behave similarly. It is most likely that site-specific signals related to local climate and site conditions caused the differences in reconstruction quality. In contrast to Vikran, tree rings from Forfjorddalen are more likely to integrate climate events outside the July-August temperature window. The starting point for improving the long Forfjorddalen reconstruction, will be to explain the growth deviations at Forfjorddalen about 1920 (positive) and 1960 (negative), in relation to the observed summer temperatures. At the oceanic limit of pine, high winter temperatures represent a stress factor. Indeed, the steep rise in growth observed around 1920 coincided with low winter temperatures, while during the decades of maximum summer temperatures and during the 1960s, winter temperatures were high. Also the winter index of the North Atlantic Oscillation is high about 1920 and low in the 1960s (Van Loon and Rogers, 1978), indicating stable winters in the former period and high cyclonic activity in coastal northern Norway during the 1960s. However, no statistical proof for the effect of winter temperatures was found in the response functions; winter conditions appear to influence the low-frequency variability of pine growth, while the year-to-year variability is determined by summer temperatures.

CLIMATE SINCE AD 1358

The reconstruction for AD 1358-1550 was based exclusively on the Forfjorddalen chronology (Figure 5). Summer temperatures were predominantly low AD 1375-1440 and then fluctuated strongly until the onset of an extraordinary long period of high temperatures between AD 1475-1540 which ended with a severely cold phase in the AD 1540s. In terms of growth, this anomaly is an analogy to the 20th century, when considerable deviations between growth and summer temperatures occurred at Forfjorddalen. Though warm summers certainly must have prevailed between AD 1475-1540, additional independent palaeoclimatic information is required to describe in more detail the climatic characteristics of the 15th and 16th century at the coast of northern Norway.

The climate during the period AD 1550-1700 is documented by the chronologies from Forfjorddalen and Stonglandseidet. In the mean reconstruction, summer temperatures were stable and close to average during AD 1550-1600 (Figure 6). The period AD 1600-1715 was dominated by three temperature cycles of about 40 year length, with minima at around AD 1605 (−1.6 standard deviations from 1874-1989 mean; 10-year low-pass filter: −0.67 SD), 1645 (−1.6 and −0.56 SD) and 1680 (−2.2 and −0.77 SD), and the three maxima appeared to be as warm as the 20th century mean. In the mean reconstruction, the cycles had nearly equal amplitudes. However, the individual reconstructions display opposite trends (Figure 5). At Stonglandseidet, the trend for July-August temperatures was negative and the later minima were more severe (AD 1641: 9.5°C, AD

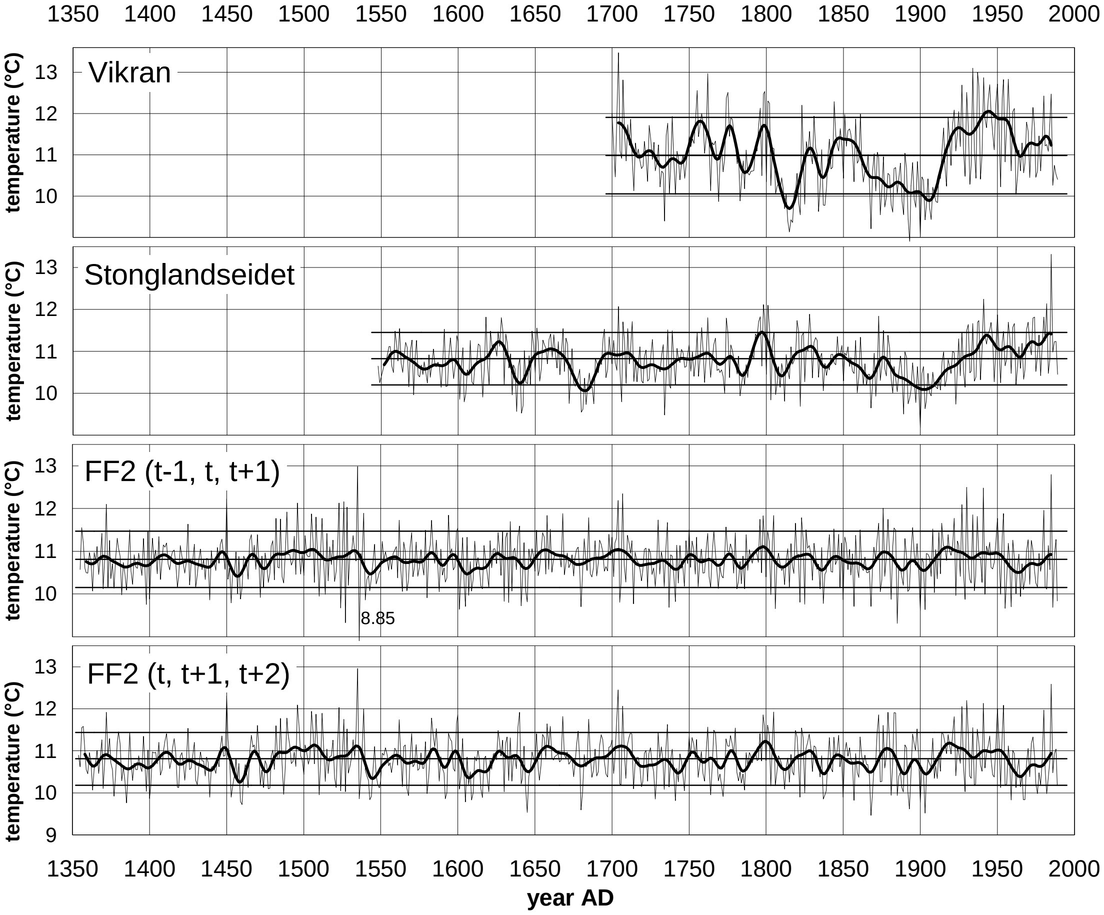

Figure 5: July-August temperatures of Tromsø reconstructed from the Vikran chronology (VIK), and Andenes July-August temperatures reconstructed from the chronologies of Stonglandseidet (STO) and Forfjorddalen (FF2). For Forfjorddalen, two alternative reconstructions are presented. The means and standard deviations for the period AD 1874-1992 are indicated. The decadal variability is shown by a 10-year low-pass filtered series (bold line).

1635-47 mean: 10.3°C; AD 1680: 9.6°C, AD 1672-88 mean: 10.2°C; Andenes AD 1961-90: 11.1°C). In contrast, in Forfjorddalen, only the AD 1601-20 minimum was distinctly developed, while the years AD 1650-1713 apparently experienced rather high summer temperatures. Considering its duration, the AD 1601-20 cold event must be regarded as the most severe of the whole reconstruction, while the third depression of the low-pass filtered series was mostly caused by the extremely cold summer AD 1680. In conclusion, from the observed growth depressions in addition to evidence for a gap in pine recruitment at AD 1575-1650 (Figure 2), the first half of the 17th century appears to have been especially cold and unfavourable for pine growth. The second half of that century can be regarded as slightly warmer, allowing pine recruitment during the warm interval AD 1650-70 and survival of young trees through the AD 1680s. This period of strong temperature fluctuations at the northern Norwegian coast fits well into the period of lowest 'Little Ice Age' temperatures as proposed for the Northern Hemisphere, AD 1570-1730 (Bradley and Jones, 1993). Therefore, further efforts are necessary to increase the chronology length and replication as well as to investigate pine regeneration at Forfjorddalen and Stonglandseidet, in order to obtain a more significant picture of the climate of the 17th century.

The mean reconstruction of July-August-temperature since AD 1710 was based on all three chronologies (Figure 6) and consists of three major phases: I) a stable cool phase AD 1714-1748, 0.23 standard deviations below the 1874-1989 mean, II) a phase of close-to-average temperatures AD 1749-1856, with high decadal variability AD 1780-1815, and III) a strong cooling trend AD 1850-1900, towards a mean at –1 standard deviations. The highest degree of variability is expressed in the Vikran reconstruction (Figure 5). The development of July-August temperatures AD 1700-1910 can be described either by a cooling trend of 0.54°C per century, or by dividing the series at AD 1805/06 into a warm 18th (mean 11.2°C) and a cool 19th century (mean 10.5°C; Tromsø July-August mean temperature 1961-90: 11.3°C). Temperatures in the second half of the 18th century fluctuated strongly with cycle lengths of ~20 years. The low-pass filtered series displayed amplitudes of about 1°C and maxima at about 11.7°C in AD 1757, 1776 and 1798. From AD 1800, temperatures dropped suddenly, culminating in AD 1815 at 9.13°C.

Considering the underestimation of temperature extremes during the calibration period by 1-1.5°C (Figure 4), the real amplitude of this event must have been even greater than the reconstructed 2.0°C (low-pass filtered) and 3.4°C (annual resolution). July-August temperatures remained below 9.5°C for four years, AD 1814-1817, and below 10.1°C for seven years, AD 1812-1818. They rose above 11°C at AD 1823/26 and stayed at this level until AD 1861. During the following 52 years, AD 1862-1913, the reconstructed July-August temperatures, with a few exceptions, stayed below 11°C (mean: 10.2°C). The early instrumental record at Tromsø thus coincided with a long cool phase, and part of the observed warming trend in the instrument record thus reflects a recovery from this negative anomaly.

At Stonglandseidet, summer temperatures during AD 1714-1780 were considerably more stable than at Vikran (Figure 5). At the former site, mean July-August temperatures AD 1714-1741 were 10.6°C, with the century minimum of 9.48°C at AD 1734. Only the last of the late 18th century temperature cycles at Vikran appeared in this reconstruction

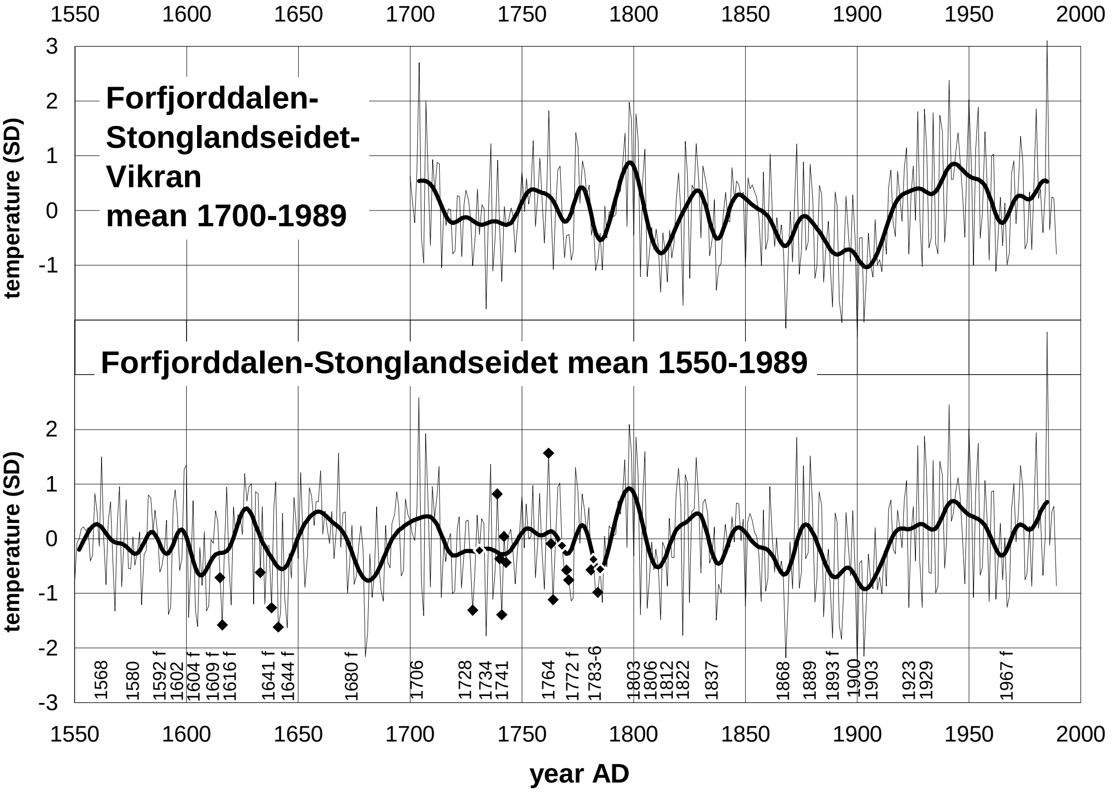

Figure 6: July-August temperatures for the coastal region of southern Troms and Vesterålen back to AD 1700, based on the mean of the reconstructions from Forfjorddalen, Stonglandseidet and Vikran. Also shown are July-August temperatures of Andenes back to AD 1550, based on the mean of the reconstructions from Forfjorddalen and Stonglandseidet. Forfjorddalen is represented by the model FF2 (t, t+1, t+2). Temperatures are expressed in standard deviations from the mean AD 1874-1992. The decadal variability is shown by a 10-year low-pass filtered series (bold line). Dates for selected cold summers are shown below the lower chronology. Years of failed or poor barley harvests (Fjærvoll, 1960; 1964) are indicated (◆).

(mean AD 1793-1802: 11.5°C), and the negative temperature anomaly of AD 1815 was not developed at all. Instead, after the cold summers of AD 1803 (9.8°C), AD 1806 (10.0°C) and AD 1812 (9.8°), the July-August temperature raised to about 11°C until AD 1833, before the onset of the cooling trend towards AD 1900. In the Forfjorddalen reconstruction, the early 19th century temperature depression was even less pronounced, while the temperature amelioration of the 1870s was rather prominent. These might be examples of decadal-scale spatio-temporal variability of summer temperature.

The low-frequency variability of chronologies and reconstructions is limited by the average segment length of the presented chronologies (Cook *et al.*, 1995), in this case about 250 years. Thus, care should be taken when comparing the summer temperatures of AD 1700-1750 or earlier with the 20th century mean. The segment length may have caused both maximum and near-minimum growth to be observed in the time period of the instrumental climate record, which in turn means that the climate reconstructions were unlikely to exceed the temperature band experienced during the recent 130 years.

Independent verification and supplementation of the dendroclimatic reconstruction may be derived from historical records, such as barley harvests (*Hordeum*) documented in tax lists from Vesterålen and Senja (Fjærvoll 1961; 1964). These records are continuous from AD 1611-1641 and AD 1714-1731 and often include comments on summer weather. Harvests were poor in the years 1615/16, good in the 1620s, failed totally in AD 1633 and 1638, and were poor again in 1641. No total failures of crop are reported for the years AD 1714-31, but bad harvests occurred in AD 1728 due to excessive rain and, in 1731, due to rain and frosts. No barley taxes are reported AD 1732-44; AD 1739-43 due to frost. Crop production became more important in the second half of the 18th century and expanded especially towards the 1790s. However, this trend was interrupted by poor barley harvests in the years 1762-64, 1768 (total failure), 1770/71, 1781/82 and 1784/85. Most, though not all, of these years coincide with cool summers in the dendroclimatic reconstruction. However, such historical data is extremely complex and requires care in interpretation. For example, the absence of records in certain years may not reflect regional climate at all, but be caused by external factors such as failure of seed crop import or changes in the taxation routines.

From the Torneträsk-chronology, northern Sweden, and from several additional climate reconstructions of the Northern Hemisphere it was concluded that the summers of AD 1570-1730 were especially cold (Briffa *et al.*, 1992; Bradley and Jones, 1993). The extent of the cold period does not differ much from the present Stonglandseidet reconstruction, where the cold period commences earlier than at Forfjorddalen. At

Torneträsk, the lowest temperatures were recorded in the early part, about AD 1580-1620 and AD 1640, which does agree with the Forfjorddalen reconstruction, but not with the Stonglandseidet reconstruction as discussed earlier in this paper. Warm periods at Torneträsk were reconstructed for AD 1360-1570, AD 1760 and AD 1820 (Briffa *et al.*, 1992; 1998a). At the Atlantic coast, the first of these periods is more restricted and does not commence before AD 1475, which is after the main temperature peaks in the Torneträsk reconstruction, AD 1410 and AD 1430. Also, the coastal warm period appears to end abruptly already in the 1540s. Also in the 18th century, the coastal temperature maximum is delayed: it occurs at about AD 1760 in the inland (Briffa *et al.*, 1992; Lindholm, 1996), but not until the 1790s at the coast.

In conclusion, past summer temperatures show similar long-term trends on both sides of the Scandes, but differ in magnitude and duration as well as in the timing of the extremes. Differences in climate continentality, standardisation techniques, and analysed tree-ring parameters may cause differences in the magnitude of recorded climate anomalies. Spatio-temporal variability in the northern Fennoscandian tree-ring record probably relates to atmospheric circulation patterns. Atlantic and Polar air masses from the western sector cause orographic precipitation at the Norwegian coast, while northern Sweden and Finland lie in the lee of the Scandes. In contrast, when cyclones move from Iceland towards southern Scandinavia, northern Fennoscandia experiences SE-winds, with rain on the eastern slope of the northern Scandes and bright skies along the coast. Whenever such synoptic situations prevail over major parts of the summer, these will be manifested in the tree-ring record. Interpreting contrasting growth rates on both sides of the Scandes in terms of atmospheric circulation patterns, northern Fennoscandia appears to have been influenced by zonal circulation about AD 1760, while dominated by south-eastern winds in the 1790s. Additionally, anomalies of North Atlantic sea surface temperature must be taken into consideration as a cause for regional differences in pine growth, due to changes of the gradient of continentality across the Scandes. A synopsis of northern Fennoscandian chronologies is expected to contribute to reconstructions of oceanographic as well as atmospheric processes in the North Atlantic region on annual to multi-decadal timescales.

CONCLUSIONS & SUMMARY

1. Three tree-ring chronologies from Scots pine, *Pinus sylvestris*, were constructed at the coast of northern Norway between the Lofoten-Vesterålen archipelago and Tromsø (Forfjorddalen AD 1358-1992, Stonglandseidet AD 1548-1994, Vikran AD 1700-1992). The two longest chronologies cover the 'Little Ice Age' (Bradley and Jones. 1993).

2. Bootstrap orthogonal regression revealed a predominant response of ring width to July-August temperatures. Differences in climate response between the localities relate to a shorter growing period at the northernmost, north-facing site (Vikran), drought sensitivity at a steep south-facing site (Stonglandseidet) and stress due to high winter temperature at the most oceanic site (Forfjorddalen).

3. Tree growth was very consistent in the region AD 1700-1910, implying summer temperature as the main growth limiting factor. Since AD 1910, the growth trends of the individual sites differ, suggesting individual responses to summer moisture and winter temperatures during warm periods.

4. The Vikran chronology contained the strongest tree-ring and climate signal. Towards the more oceanic south-west, tree-ages and chronology length increase, while low-frequency variability in tree-rings and climate reconstruction decrease.

5. July-August mean temperatures at the coast of northern Norway were reconstructed back to AD 1358. High temperatures prevailed during the long period AD 1470-1540. The 17th century, along with the 1450s, 1540s and AD 1880-1910, is the coldest period of the reconstruction. Three strong fluctuations in summer temperatures occurred during that century, with minima around AD 1605, 1640 and 1680. Poor evidence for pine regeneration at Forfjorddalen AD 1575-1650 supports the hypothesis of low temperatures in the first half of the 17th century.

6. At Forfjorddalen, further efforts have to be made to explain the climate response in the 20th century, as well as to assess the extent of the proposed logging activity and its implications for the observed growth and climate trend in the 17th century.

7. Reconstructed temperatures showed similar long-term trends on both sides of the Scandes, but differed in the magnitude and timing of the extremes. These differences should be the focus of further studies on past atmospheric circulation patterns and North Atlantic sea surface temperatures.

REFERENCES

Aandstad, S. 1939: Die Jahresringbreiten einiger seltenen Kiefern in Steigen, Nordland. *Nytt Magasin for Naturvitenskapene* 79, 127-40.

Aniol, R.W. and **Eckstein, D.** 1984: Dendroclimatological studies at the northern timberline. In Mörner, N.-A. and Karlén, W., editors, *Climatic changes on a yearly to millennial basis*. Dordrecht: D. Reidel Publishing Company, pp. 273-79.

Aune, B. 1993: Air temperature normals, normal period 1961-1990. Norwegian Meteorological Institute, Oslo. *DNMI-report* 02/93 klima, 63 pp.

Bartholin, T.S. and **Karlén, W.** 1983: Dendrokronologi i Lapland. *Meddelanden fra det Dendrokronologiska Sällskapet* 5, 3-16.

Bradley, R.S. and **Jones, P.D.** 1993: 'Little Ice Age' summer temperature variations: their nature and relevance to recent global warming trends. *The Holocene* 3(4), 367-76.

Briffa, K.R. 1994: Mid and late Holocene climate change: evidence from tree growth in northern Fennoscandia. In Funnell, B.M. and Kay, R.L.F., editors, *Palaeoclimate of the last glacial/interglacial cycle*. Natural Environment Research Council Special Publications 94(2), 61-65.

Briffa, K.R., Bartholin, T.S., Eckstein, D., Jones, P.D., Karlén, W., Schweingruber, F.H. and **Zetterberg, P.** 1990: A 1,400-year tree-ring record of summer temperatures in Fennoscandia. *Nature* 346, 434-39.

Briffa, K.R. and **Jones, P.D.** 1990: Basic chronology statistics and assessment. In Cook, E.R. and Kairiukstis, L.A., editors, *Methods of Dendrochronology: applications in the environmental science*. Dordrecht: Kluwer Academic Publishers, pp. 137-52.

Briffa, K.R., Jones, P.D., Bartholin, T.S., Eckstein, D., Schweingruber, F.H., Karlén, W., Zetterberg, P. and **Eronen, M.** 1992: Fennoscandian summers from AD 500: temperature changes on short and long timescales. *Climate Dynamics*, 111-19.

Briffa, K.R., Jones, P.D., Pilcher, J.R. and **Hughes, M.K.** 1988a: Reconstructing summer temperatures in northern Fennoscandia back to A.D. 1700 using tree-ring data from Scots pine. *Arctic and Alpine Research* 20(4), 385-94.

Briffa, K.R., Jones, P.D. and **Schweingruber, F.H.** 1988b: Summer temperature patterns over Europe: A reconstruction from 1750 A. D. based on maximum latewood density indices of conifers. *Quaternary Research* 30, 36-52.

Briffa, K.R., Schweingruber, F.H., Jones, P.D., Osborn, T.J., Harris, I.C., Shiyatov, S.G., Vaganov, E.A. and **Grudd, H.** 1998a: Trees tell of past climates: but are they speaking less clearly today? *Philosophical Transactions of the Royal Society of London* B 353, 65-73.

Briffa, K.R., Schweingruber, F.H., Jones, P.D., Osborn, T.J., Shiyatov, S.G. and **Vaganov, E.A.** 1998b: Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. *Nature* 391, 678-681.

Cook, E.R. 1985: *A time-series analysis approach to tree-ring standardization*. PhD thesis, University of Arizona, Tucson, 171 pp.

Cook, E.R., Briffa, K.R., Meko, D.M., Graybill, D.A. and **Funkhouser, G.** 1995: The 'segment length course' in long tree-ring chronology development for palaeoclimatic studies. *The Holocene* 5(2), 229-37.

Cook, E.R., D'Arrigo, R.D. and **Briffa, K.R.** 1998: A reconstruction of the North Atlantic Oscillation using tree-ring chronologies from North America and Europe. *The Holocene* 8(1), 9-17.

Cook, E.R. and **Kairiukstis, L.A.,** editors 1990: *Methods of Dendrochronology: applications in the environmental science*. Dordrecht: Kluwer Academic Publishers, 393 pp.

D'Arrigo, R.D., Cook, E.R., Jacoby, G.C., Jr. and **Briffa, K.R.** 1994: NAO and sea surface temperature signatures in tree-ring records from the North Atlantic sector. *Quaternary Science Reviews* 12, 431-40.

D'Arrigo, R.D. and **Jacoby, G.C.** 1993: Secular trends in high northern latitude temperature reconstructions based on tree rings. *Climatic Change* 25, 163-77.

Eckstein, D. and **Bauch, J.** 1969: Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens zur Analyse seiner Aussagesicherheit. *Forstwissenschaftliches Centralblatt* 88, 230-50.

Eckstein, D., Hoogesteger, J. and **Holmes, R.L.** 1991: Insect-related differences in growth of birch and pine at northern treeline in Swedish Lapland. *Holarctic Ecology* 14, 18-23.

Efron, B. 1979: Bootstrap methods: another look at the jackknife. *Annals of Statistics* 9, 139-72.

Eide, E. 1926: Om sommervarmens innflytelse på årringbredden (Über Sommertemperatur und Dickenwachstum im Fichtenwald). *Meddelelser fra Det Norske Skogforsøksvesen* 7, 87-104.

Erlandsson, S. 1936: Dendro-Chronological studies. Stockholm Högskolas Geokronologiska Institution, *Data* 23, 119 pp.

Fjærvoll, K. 1961: *Korndyrkinga i Hålogaland i gammal tid, 1500- og 1600-åra*. Tilleggsbok til Håløygminne. Svorkmo Prenteverk, 127 pp.

— 1964: *Korndyrkinga i Troms fylke i 1700-åra med tilknytting til nyare tid (Senien og Tromsen Fogderi)*. Bodø: Nordland Boktrykkeri, 110 pp.

Førland, E.J. 1993: Precipitation normals, normal period 1961-1990. Norwegian Meteorological Institute, Oslo. *DNMI-report* 39/93 klima, 63 pp.

Frich, P., Alexandersson, H., Ashcroft, J., Dahlström, B., Demarée, G.R., Drebs, A., Engelen, A.F.V.v., Førland, E.J., Hanssen-Bauer, I., Heino, R., Jónsson, T., Jónasson, K., Keegan, L., Nordli, P.Ø., Schmith, T., Steffensen, P., Tuomenvirta, H. and **Tveito, O.E.** 1996: *North Atlantic Climatological Dataset (NACD Version 1) - Final Report*. Danish Meteorological Institute, Copenhagen. *Scientific Report* 96-1, 47 pp.

Fritts, H.C. 1976: *Tree rings and climate*. London: Academic Press, 567 pp.

Guiot, J. 1985: The extrapolation of recent climatological series with spectral canonical regression. *Journal of Climatology* 5, 325-35.

Guiot, J. and **Goeury, C.** 1996: PPPBase, a software for statistical analysis of paleoecological and paleoclimatological data. *Dendrochronologia* 14, 295-300.

Guttormsen, H. 1990: *Sortlands historie. Bind I - Swartalande*. Sortland Kommune, 280 pp.

Hesselmann, H. 1904: Om tallens diametertillväxt under de sista tio åren. *Meddelanden från Statens Skogsförsöksanst.* 1904(1), 45-53.

Holmes, R.L., Adams, R.K. and **Fritts, H.C.** 1986: Tree-ring chronologies of western North America: California, eastern Oregon and northern Great Basin, with procedures used in the chronology development work, including users manuals for computer programs COFECHA and ARSTAN. Laboratory of Tree-Ring Research, University of Arizona, Tucson. *Chronology Series* VI, 182 pp.

Hustich, I. 1945: The radial growth of the pine at the forest limit and its dependece on the climate. *Societas Scientiarum Fennica, Commentationes Biologicae* 9(11), 1-30.

Hustich, I. and **Elfving, G.** 1944: Die Radialzuwachsvariationen der Waldgrenzkiefer. *Societas Scientiarum Fennica, Commentationes Biologicae* 9(8), 1-18.

Kirchhefer, A.J. 1998: Climate and site effects on tree-rings of *Pinus sylvestris* L. in northernmost Norway - an exploratory pointer-year study. *AmS-Varia* 32, 15-28.

Kirchhefer, A.J. and **Vorren, K.-D.** 1995: Årringer på furu, *Pinus sylvestris* L., som kilde for klimainformasjon i Vesterålen, Nord-Norge (Tree rings of Scots pine, *Pinus sylvestris* L., a source of climate information in Vesterålen, northern Norway). *AmS-Varia* 24, 79-85.

Kolmodin, G. 1923: Tillväxtundersökningar i Norra Dalarna. *Svenska Skogsvårdsföreningens Tidskrift* 1923, Serien A, 1-35.

Kullman, L. 1996: Structural population dynamics of pine (*Pinus sylvestris* L.) during the past 500 years close to the tree-limit in northern Sweden. In Frenzel, B., Birks, H.H., Alm, T. and Vorren, K.-D., editors, *Holocene treeline oscillations, dendrochronology and palaeoclimate*. Stuttgart: Gustav Fischer Verlag. *Palaeoclimate Research* 20, 75-92.

Lindholm, M. 1996: Reconstructions of past climate from ring-width chronologies of Scots pine (*Pinus sylvestris* L.) at the northern forest limit in Fennoscandia. PhD thesis. University of Joensuu. *Publications in Sciences* 40, 169 pp.

Moen, A. 1998: *Nasjonalatlas for Norge: Vegetasjon*. Hønefoss: Statens kartverk, 200 pp.

Ording, A. 1941: Årringundersøkelser på gran og furu. *Meddelelser fra Det Norske Skogforsøksvesen* VII(25), 101-354.

Ruden, T. 1987: Hva furuårringer fra Forfjorddalen kan fortelle om klimaet i Vesterålen 1700-1850 (What annual rings of Scots pine (*Pinus sylvestris*) from Forfjorddalen can tell about the climate in Vesterålen 1700-1850). Norwegian Forest Research Institute. *NISK rapport* 4/87, 12 pp.

Schweingruber, F.H. 1985: Dendro-ecological zones in the coniferous forests of Europe. *Dendrochronologia* 3, 67-75.

Schweingruber, F.H., Bräker, O.U. and **Schär, E.** 1987: Temperature information from a European dendroclimatological sampling network. *Dendrochronologia* 5, 9-22.

Schweingruber, F.H. and **Briffa, K.R.** 1996: Tree-ring density networks for climate reconstruction. In Jones, P.D., Bradley, R.S. and Jouzel, J., editors, *Climatic variations and forcing mechanisms of the last 2000 years*. Berlin: Springer-Verlag. *NATO ASI Series* I 41, 43-66.

Schweingruber, F.H., Briffa, K.R. and **Jones, P.D.** 1991: Yearly maps of summer temperatures in Western Europe from A.D. 1750 to 1975 and Western North America from 1600 to 1982 - results of a radiodensitometrical study on tree rings. *Vegetatio* 92, 5-71.

Sirén, G. 1961: Skogsgränstallen som indikator för klimatfluktuationerna i norra Fennoskandien under historisk tid. *Communicationes Instituti Forestalis Fenniae* 54(2), 1-66.

Thun, T. and **Vorren, K.-D.** 1996: Short dendroseries from northern Norway reflect oceanic and subcontinental climates. In Frenzel, B., Birks, H.H., Alm, T. and Vorren, K.-D., editors, *Holocene treeline oscillations, dendrochronology and palaeoclimate*. Stuttgart: Gustav Fischer Verlag. *Palaeoclimate Research* 20, 120-26.

Till, C. and **Guiot, J.** 1990: Reconstruction of precipitation in Morocco since 1100 A.D. based on *Cedrus atlantica* tree-ring widths. *Quaternary Research* 33, 337-51.

Van Loon, H. and **Rogers, J.C.** 1978: The seesaw in the winter temperatures between Greenland and northern Europe: Part I: General description. *Monthly Weather Review* 106, 296-310.

Wallén, A. 1917: Om temperaturen og nedbördens inverkan på granens och tallens höjd- och radietillväxt å Stamnäs kronopark 1890-1914. *Skogshögskolan 1917: Festskrift vid Skoghögskolans invigning 3 maj 1917*, pp. 413-427.

Wigley, T.M.L., Briffa, K.R. and **Jones, P.D.** 1984: On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Climate and Applied Meteorology* 23, 201-13.

Zetterberg, P., Eronen, M. and **Lindholm, M.** 1996: Construction of a 7500-year tree-ring record for Scots pine (*Pinus sylvestris*, L.) in northern Fennoscandia and its application to growth variation and palaeoclimatic studies. In Spieker, H., Mielikäinen, K., Köhl, M. and Skovsgaard, J.P., editors, *Growth trends in European forests*. Berlin: Springer-Verlag. *European Forest Institute Research Report* 5, 7-18.

Submitted to *The Holocene*, August 7th 1999, in press