Contrasting Tree-ring Data with Fire Record in a Pine-dominated Landscape in the Komi Republic (Eastern European Russia): Recovering a Common Climate Signal

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For the period 1420–1960 we contrasted fire events reconstructed at 14 sites distributed over a 50 km × 50 km area in the central part of the Komi Republic (European Russia) with a set of tree-ring width chronologies of Scots pine (*Pinus sylvestris* L.), developed for the same area. Our aim was to infer common climatic information contained in tree-ring variables and independently dated fire events with the help of a superposed epoch analysis.

The strongest weather–growth link was shown for the latewood width, which was positively correlated with the temperature in April–May and July–August of the current growth season and with previous year precipitation in July–August. Earlywood width was positively affected by previous year precipitation in May and November.

The relationship between yearly ring variables and multiple-site fire events was dependent on the seasonal timing of fire events as recorded in the scars. In years with early-season fires (which made up 37% of all fires dated with seasonal resolution) total ring width was significantly narrower. In years with late-season fires (63%) total ring width, earlywood, and latewood width were significantly wider. Years with late-season fires tended to be associated with local highs of the latewood width chronologies over 1400–1960, which implied a link between decadal-scale climate variation and fire regime of the area.

Keywords latewood, earlywood, chronology, seasonal dating, boreal, weather control, natural disturbance, climate

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1 Introduction

In conifer-dominated ecosystems, climatic and weather variation drives natural fire activity (Bergeron and Archambault 1993, Korovin 1996, Flannigan at al. 1998, Pitkänen and Huttunen 1999, Grissino-Mayer and Swetnam 2000). Linking dendrochronological reconstructions of climatic variation and independent record of fire activity provides a useful tool for the analysis of climate-fire interaction over century and millennia long periods (Swetnam and Betancourt 1990, Swetnam 1993). Several factors naturally limiting the possibilities of such analysis include

1) differences in the rate and timing of weather processes which ultimately lead to fire ignition and its propagation (Johnson 1992) on one hand, and formation of tree-rings (Fritts 1976), on the other,
2) absence of a reliable proxy for the decadal and century-long variation in fuel characteristics,
3) typically local nature of fire histories compared with the more regional nature of climatic information reconstructed from tree-rings; and, finally
4) anthropogenic influence on the forest, disturbing the natural weather/climate signal in fire chronologies (e.g. Lehtonen and Kolström 2000, Niklasson and Granström 2000, Heyerdahl et al. 2001).

Dendrochronologically dated fire is a means to reconstruct past fire activity with annual or even seasonal resolution (Fritts and Swetnam 1989). Laborious work associated with data sampling and dating largely precludes dense fire history networks of sites over large regions. However, using tree-ring chronologies makes it possible to assess how well a particular fire event corresponded to independently reconstructed climate/weather settings for a season/year when a fire occurred. In this paper, we contrast tree-ring data from chronologies of Scots pine (*Pinus sylvestris* L.) obtained in the southeastern part of the Komi Republic, Eastern European Russia, with dendrochronologically reconstructed fire events at 14 sites distributed over the territory of 50 km × 50 km in the same region. The primary goal was to establish a relationship between tree-ring variables and independently dated fire events and, in this way, to infer common climatic information contained in both datasets.

2 Methods

2.1 Study Area

The Komi Republic is the most forest rich region in the northeastern part of European part of Russia (Fig. 1). It occupies 415 900 km^2 within two major land shields – the Russian shield in the southwestern part of the republic and Pechora shield in its northeastern part (Dedeev 1997) – with moraine and surfaced loams being the most typical soil types (Zaboeva 1997).

The forested area of the republic totals around 300 000 km^2, which constitutes 4.1% of all Russian forested area (Komi 1981). Climatically, the region lies within Arctic, Atlantic-Arctic and Atlantic-continental provinces (Republic of Komi 1997). Annual average temperature varies between +1 °C in the southern part of the republic and –6 °C in its northern part with respective lengths of the growth season (days with average daily temperature above 10 °C) being between 110 and 45 days. Annual sum of precipitation decreases from 700 mm in the south down to 450 mm in the north. Accumulation of thick snow cover (70–80 cm) is characteristic for the winter period lasting for 130–200 days.

Middle and northern taiga forests belonging to middle boreal subzone (Ahti et al. 1968) prevail in the vegetation cover of Komi with the exception of the mountainous part, which is dominated by forest-tundra and tundra ecosystems (Larin 1997). Field sampling was done in the southeastern part of the republic, close to and within southern part of Pechoro-Ilich state reserve with its administrative center in Jaksha village (61°05´N; 57°00´E), located in the valley of Pechora river. Pechoro-Ilich state reserve occupies 721 322 ha and with its buffer zone (497 500 ha) makes up 2.92% of the total territory of the Komi Republic (Lesnoe khozjaistvo 1999). For this area average daily temperature starts exceeding 10 °C during the first decade of June and falls below this value in the first week of September. Complete snow melting in the pine forests occurs in mid-May and the first snow cover in the first week of October.

The pine forests of Komi have been primarily exploited as a source of timber and game. The human impact on the forests considerably increased since the middle of 18th century as a

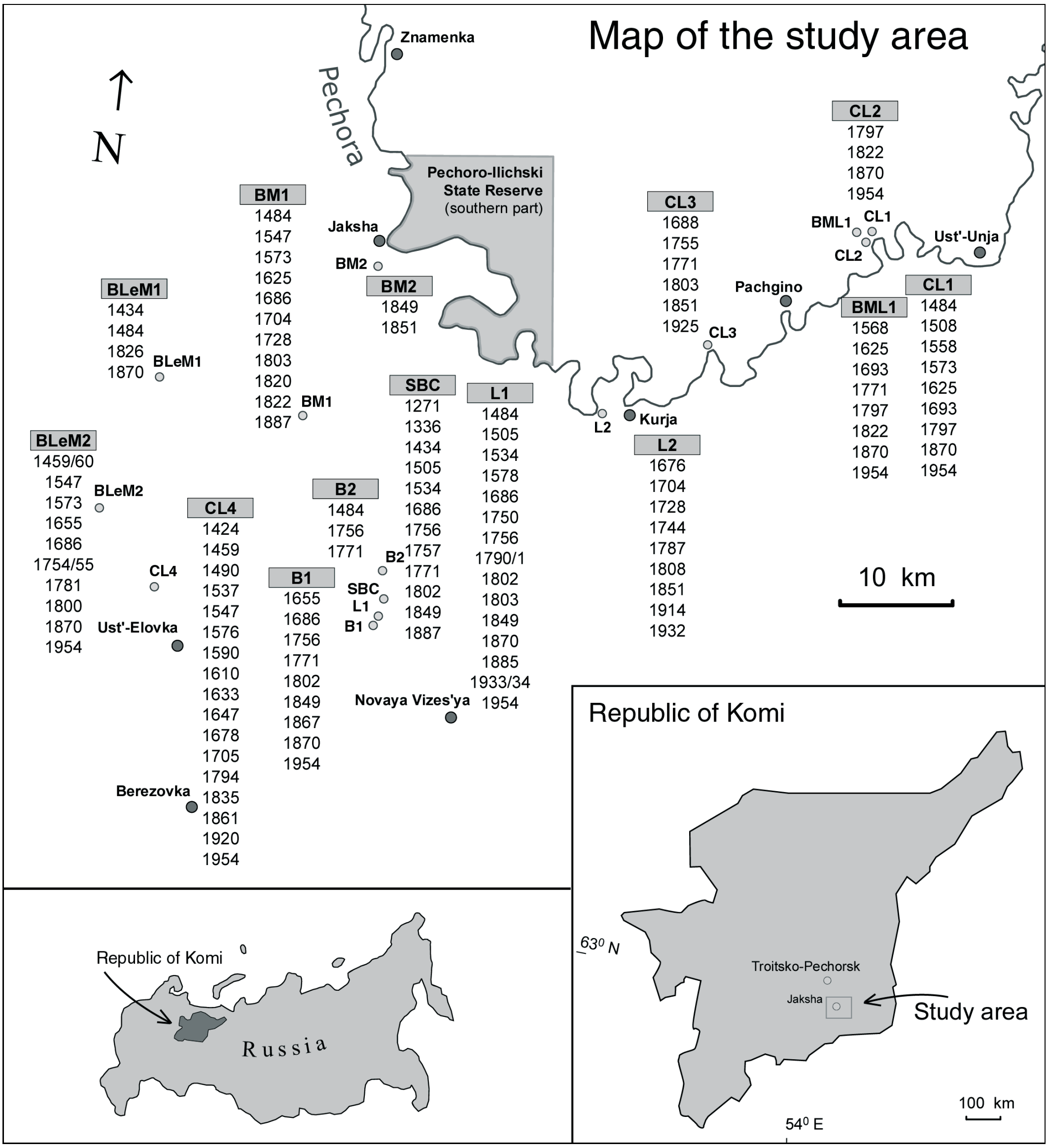

Fig. 1. Geographical location of the study area, climate station (Troitsko-Pechorskoe), and complete site fire histories. Data used for building tree-ring chronologies were from fire history sites and sites (not shown) within southern part of Pechoro-Ilichski state reserve. Site codes refer to Table 1.

result of progressively more mechanized timber exploitation (Larin 1997). However, the republic still possesses large areas of relatively undisturbed pine- and spruce-dominated forests where natural stand dynamics dominate (Anufriev 2000).

2.2 Acquisition of the Weather Data

Hourly datasets from Troitsko-Pechorskoe climate station (WMO station number 23711, Vose et al. 1992, Razuvaev et al. 1995) were used to acquire monthly values for mean monthly tem-

Table 1. Description of study sites. Tree species: PSyl – *Pinus sylvestris*, PO – *Picea obovata*, BP – *Betula pubescens*, LS – *Larix sibirica*, PSib – *Pinus sibirica*. Numbers in the second column refer to visually estimated proportion (in fractions of ten) of basal area, accounted for by a tree species within a site.

Site no.	Site type and stand composition	Number of samples taken	Site code	Site types
1	Lichen, 10 PSyl	12	L1	Cowberry-lichens
2	Blueberry, 9 PSyl : 1 PO	3	B1	Blueberry
3	Cowberry-lichen, 10 PSyl	17	CL1	Cowberry-lichens
4	Cowberry-lichen, 10 PSyl	5	CL2	Cowberry-lichens
5	Blueberry–green moss–lichen, 10 PSyl	8	BML1	Blueberry
6	Cowberry-lichen, 10 PSyl	5	CL3	Cowberry-lichens
7	Lichen, 10 PSyl	5	L2	Cowberry-lichens
8	Blueberry–green moss, 8 PSyl : 1 LS : 1 BP	11	BM1	Blueberry-moss
9	Blueberry, 10 PSyl	11	B2	Blueberry
10	Blueberry–*Ledum*–green moss, 10 PSyl	12	BLeM1	Blueberry-moss
11	Blueberry–*Ledum*–green moss, 6 PSyl : 3 PO : 1 PSyb	19	BLeM2	Blueberry-moss
12	Cowberry-lichen with green-moss and *Ledum*, 10 PSyl	15	CL4	Cowberry-lichens
13	Blueberry–green moss, 10 PSyl	3	BM2	Blueberry-moss
14	*Sphagnum*–blueberry–cowberry, 10 PSyl	15	SBC	Blueberry-moss

perature and total monthly precipitation. Observation period for this station covered years 1897 through 1992. The climate record was checked for inconsistencies and inhomogeneities (Razuvaev et al. 1995).

2.3 Chronology Development

Cross sections and cores of Scots pine (*Pinus sylvestris* L.) were taken from stumps, dead, and live trees at 14 sites within a 50 km × 50 km area with approximate centre being in the Jaksha village (61°49.5´N, 56°50.6´E, Fig. 1). Samples were dried, sanded, and crossdated by using pointer years and fire scars (Stokes and Smiley 1968). Although some of the samples used for fire scar dating were used for chronology development, a careful sample selection was done so as to avoid ring sequences showing obvious non-climatic fire-related pattern of releases/depressions. Both earlywood and latewood width were measured using the Aniol measuring stage controlled by the CATRAS software (Aniol 1996). Boundaries between early- and latewood were determined according to the differences of colour, cell size, and relative cell wall thickness (Kalela-Brundin 1999). Dating of single-tree chronologies was verified through application of two computer programs: CATRAS (Aniol 1983) and COFECHA. The latter program is a part of the International Tree-Ring Data Bank Program Library (Grissino-Mayer et al. 1997, Holms 1999).

To remove the non-climatic trends in width increments, single series were double detrended through the use of negative exponential and linear functions within the ARSTAN program (Grissino-Mayer et al. 1997). For the purpose of superposed epoch analysis, only residual chronologies of total ring width, early- and latewood were selected. To further strengthen high-frequency variability of residual chronologies, their autocorrelation at lag 1 was removed through autoregressive modeling. For the purpose of decadal-scale analysis of climate-fire link, ARSTAN chronologies were used in which a cubic smoothing spline was applied to preserve 50% of the variance contained in the measurement series at a wavelength of 128 years. Chronologies included 50 single-tree series for ring-width and latewood chronologies, and 44 for the earlywood chronology. Part of the chronologies covering the period 1897–1992 was used for the response function analysis of climate-growth interactions. Period 1420 through 1960 was utilised for the superposed epoch analysis (Fig. 2). To assess the strength of the common signal in chronologies, signal-to-noise ratio and expressed population signal (EPS, Wigley et al. 1984), the

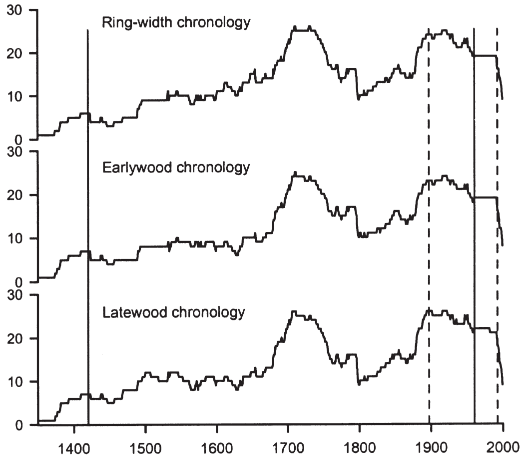

Fig. 2. Internal replication of pine ring-width, earlywood and latewood width chronologies. Dotted vertical lines showed the period used for the response function analysis and solid lines the period used in superposed epoch analysis.

correlation between the sample chronology and the theoretical population chronology based on an unlimited number of samples, were assessed for all residual chronologies.

2.4 Reconstruction of Fire History

Sampling sites were located in a way to represent the pattern of fire occurrence of a relatively large area and to make it possible to record large-scale fire events. We selected sites representing different forest types and having multi-scarred living and dead pine trees. Through crossdating (Stokes and Smiley 1968), fire scars were assigned a calendar year, and in most of the cases, a season (Baisan and Swetnam 1990, Johnson at al. 1999). Years with the scars found in the earlywood were later referred to as years with 'early-season fires'. Similarly, scars in the latewood denoted the years with 'late-season fires'. Years with unclear seasonal dating and with fire scars occurring at the border of early and latewood were removed from the analysis. Due to the advent of fire suppression in the last century and, possibly, sampling bias, no fires have been observed at the studied sites since 1954 that did not allow to extend the analyzed time frame till the end of the 20th century.

2.5 Statistical Analysis

Response function analysis (Cook and Kairiukstis 1990) was applied to find out monthly weather variables significantly affecting pine growth. The analyses done with the help of the DendroClim program (Biondi 1997) used mean monthly temperature and total monthly precipitation for the previous May through the current year August.

Superposed epoch analysis was used to evaluate the goodness of fit between tree ring chronologies and fire events for the period 1420 through 1960. Only fire events recorded at more than 20% of all sites *and* at least at three sites were included in the analysis. By doing so we assumed that annual synchronicity of fire occurrence over the studied area is more a product of weather settings than of human activities (Swetnam 1993, Korovin 1996). Values of residual chronologies for the years with the dated fires and lagged years (±3 years) were averaged and plotted separately for the early- and late-season fires. Bootstrap method was applied to produce estimates of statistical significance of observed departures from mean calculated (Efron and Tibshirani 1994). Empirical 2.5 and 97.5 percentiles of the distribution were obtained through re-sampling of the original distribution 1000 times.

3 Results

3.1 Monthly Weather Variables vs. Chronologies

Signal-to-noise ratios for residual chronologies were 5.21, 5.75, and 5.58 for total, early- and latewood width chronologies. Respectively, EPS values for these chronologies were 0.84, 0.85 and 0.85. EPS value of 0.80 was attained with the sample of six trees by total width chronology since 1410, by earlywood and latewood chronologies since 1393.

The strongest weather–growth link was shown for the latewood width, which was positively

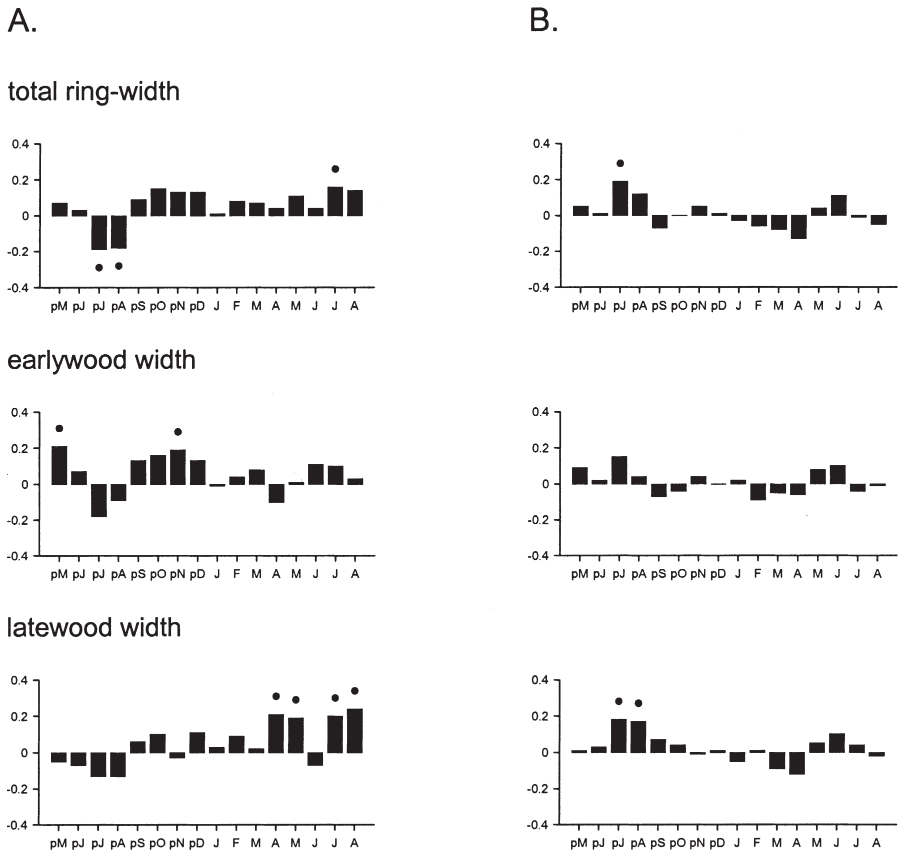

Fig. 3. Response function analysis of Scots pine chronologies developed for the Jaksha area. A – temperature, B – precipitation. Lower case 'p' denotes months in the year previous to the current year growth season. Dots point to response function coefficients significant at $p < 0.05$.

Table 2. List of years with dated fires in the studied sites since 1420. Bold letters refer to multi-site fire events, i.e. years with fires recorded at more then 20% of all sites and at least at three sites with fire chronologies covering a particular year. Unclear seasonal dating was due to narrow rings, erosion of fire scars, and location of fire scar at the border of the early- and latewood. No fires have been recorded at the sites since 1954.

Period	Fire scar is located in		Unclear seasonal dating
	Earlywood	Latewood	
1400–1499	1434	1424, 1459, **1484**, 1490	1460/59
1500–1599	1508, 1537, 1558, **1573**	1503, 1568, 1576, 1578	1505, 1534, 1547
1600–1699	**1625**, 1647, 1693	1678, **1686**	1610, 1633, 1655, 1676, 1688/87
1700–1799	1704, 1755, 1787, **1797**	1705, 1728, 1744, 1750, **1756**, 1757, **1771**, 1794	1754/55, 1790/91
1800–1899	1803, 1808, **1870**	1802, 1826, 1835, **1849**, 1851, 1861	1822, 1887
1900–1960	1925	1920, 1932, **1954**	1914, 1933/34
Total	16	27	15

correlated with the temperature in April–May and July–August of the current growth season (Fig. 3) and with previous year precipitation in July–August. Earlywood width was positively affected by previous year precipitation in May and November. As to the total ring width, cooler and wetter previous year summer used to result in better growth during the current year.

Total ring-width showed negative response to previous year summer temperature and positive response to the current year July temperature and previous year July precipitation (Fig. 3). Growth of earlywood was positively affected by previous year temperature in May and November. Latewood width showed strong and positive correlation with current year summer temperatures and less strong correlation with previous year precipitation in July–August.

3.2 Fire vs. Tree-ring Chronologies

Fires producing scars located in the latewood portion of the rings dominated (Table 2). The first

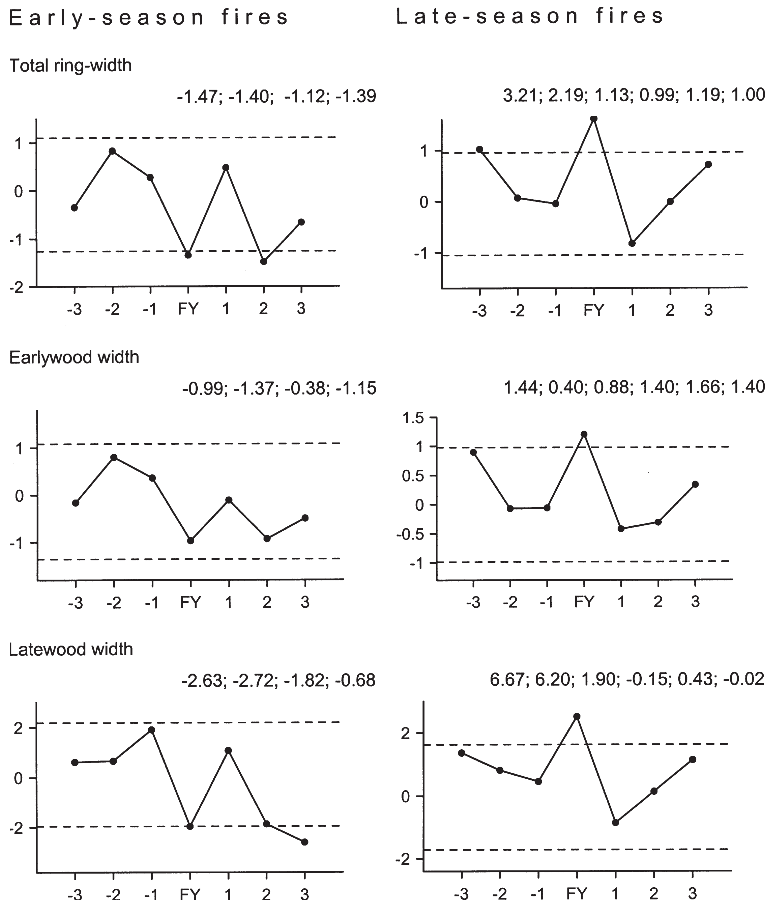

Fig. 4. Superposed epoch analyses with Scots pine width chronologies and multi-site fire events (4 early-season events and 6 late-season events) in the Jaksha area. Data are departures of total ring-width, early- and latewood residual chronologies during fire and lagging years. Dotted lines show 2.5% and 97.5% confidence intervals estimated through bootstrap procedure. Numbers above each graph are actual departures of residual chronologies during multi-site fire years.

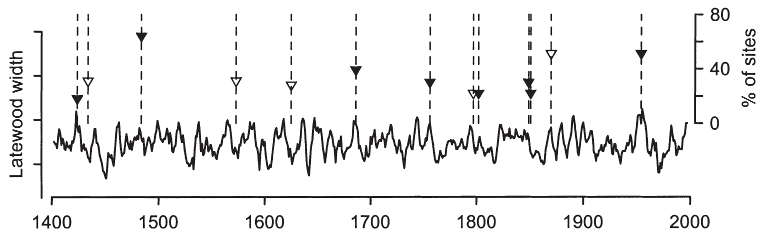

Fig. 5. Scots pine latewood width chronology contrasted with the composite fire chronology of early- and late-season multi-site fires events for the Jaksha area. The 1434 early-season fire was recorded in two sites and was plotted as being the first early-season fire in the studied interval. The 1424 late-season fire that was recorded only in one site was plotted as being the first late-season fire. The chronology is 5-year running average of ARSTAN chronology assumed to preserve low-frequency climate-related variability.

and the last fires included in the analysis were both late-summer fires occurred in 1424 and 1954, respectively. Depending on the seasonal timing of multi-site fire events, weather conditions of a fire year manifested themselves differently in the tree-ring record (Fig. 4). In years with early-season fires (4 multi-site events) total ring width was below lower 2.5% bootstrap-derived distribution limit. In years with late-season fires (6 multi-site events) total ring width, earlywood, and latewood width were above the upper 97.5% bootstrap-derived distribution limit. A review of departures used to obtain mean values for fire and lagging years did not give reasons to suspect the patterns being a result of outlier-related effect (Fig. 4). However, in the case of total and latewood widths and late-season fires the departures showed rather high values for the first two events and dropped considerably for more recent events. Several significant departures found for non-fire years did not show any consistent pattern and were considered to be of spurious nature.

To assess the relationship between fire and chronology datasets at decadal perspective, latewood width chronologies were plotted against late- and early-season multi-site fire events (Fig. 5). The resulting picture suggested a general association of fire years with local highs in the residual chronologies, six out of eight multi-site fire years being located at local highs in latewood width chronology.

4 Discussion

4.1 Relationship between Growth and Monthly Weather Variables

Temperature during the current growing season positively affected the total ring width and latewood width of Scots pine. This is in accordance with the results of other studies highlighting the positive impact of temperature on growth of conifers in the boreal zone (Jonsson 1969, Briffa et al. 1988, Miina 2000 and references inside). In this study, the positive impact of temperature was especially evident in the case of latewood width that pointed to the important role of temperature affecting pattern of lignin distribution within a ring and the rate of cell expansion (Kalela-Brundin 1999).

Higher mid-summer aridity in the previous year was apparently negative for the growth of pine in the coming year as suggested by the negative correlation between total ring width and previous year temperatures in July–August and positive with previous year July precipitation. The same impact of precipitation was also found for Scots pine in eastern Finland (Miina 2000). Lack of significant correlations between earlywood width and current year temperature in pine (Fig. 3) have also been reported earlier (Mikola 1950). However, we found a positive impact of previous year temperatures on earlywood growth suggesting that formation of earlywood was controlled by the amount of carbohydrate reserves building-up during the previous season.

No significant relationship between precipitation in the current growth season and growth was found in this study. The similar result was obtained for the pine growth in eastern Norway (Kalela-Brundin 1999). An analysis of pine growth in Sweden (Jonsson 1969) showed that response of ring-width to this parameter might be non-linear and, therefore, might be difficult to evaluate using methods assuming linear weather–growth relationship (as for example, response function analysis).

4.2 Relationship between Fire and Tree-ring Chronologies

By showing differences in the relationship between ring-width and occurrence of early- vs. late-summer fires this study demonstrates the importance of the seasonal resolution in the fire chronologies. Such differences imply that predictive power of a tree-ring width chronology in respect with fire activity could be questioned if no seasonal data on fire activity was used during proxy calibration.

Years with both early- and late-season multi-site fires produced significant width departures that pointed to climatic control over occurrence of such events (Fig. 4). In respect to the early-season fire years, significant negative departure of total ring width might be explained by high aridity at the beginning of the growth season, negatively affecting cell expansion. In respect to the late-season fires, all pine chronologies showed a strong association between positive growth anomalies and the occurrence of multi-site fires (Fig. 4). This is probably a result of strong temperature control over radial growth on one hand and lightning ignitions on the other (Granström 1993, Nash and Jonson 1996). Latewood width and total ring width showed slightly larger absolute departures than earlywood width. This could be a result of earlywood growth being to a larger extend a function of previous year weather conditions (Fig. 3, Kalela-Brundin 1999). Although we did not conduct any formal analysis or comparison of the fire years in Jaksha with other areas, none of the Jaksha multi-site fire years coincided with large fires in the Bjurholm area in northern Sweden (Niklasson and Granström 2000) or with eastern Finnish fire histories approx. 1500–2000 km to the west of Jaksha area (Lehtonen and Kolström 2000), which are the two published fire chronologies closest to the Jaksha area.

Decadal-scale climatic variability represented by latewood width chronology showed some association with two types of fire events (Fig. 5). The most evident trend was found in respect with late-season fires, which appeared to occur during the periods with local highs of latewood chronology. The result possibly indicates a link between decadal-scale increases in summer temperature and fire regime of the area. The pattern of association between early-season fires and latewood width chronology was more obscure. Except for the last event in 1870, early-season fires tended to occur in local troughs of the chronology. Our limited dataset makes it difficult to discuss this in further detail although we speculate that atmospheric circulation patterns might differ between years with early- and late-season multi-site fires.

We show here that climate has exerted some influence over fire events in Jaksha landscape. It remains uncertain if this holds true also for the larger region, which can be tested only with considerably larger data sets collected at regional scales, such as in studies by Swetnam and Betancourt (1990, 1998), and Kitzberger and Veblen (1997). Due to the spring snow melt it is likely that extreme fuel conditions promoting large fires will more often occur in late summer than in early summer (Table 2), thus the climatic control over fuel conditions may be stronger in the high-late season than in the beginning of it. However, the fire activity does not solely depend on the fuel characteristics but also on the dynamics of lightning ignitions. In Canada, large forest fires occur typically in high summer (Stocks et al. 2002) due mainly to lightning ignitions. In Sweden, lightning ignitions peak in high summer (Granström 1993) but data on fire sizes vs. seasons for natural conditions is lacking for the region. We do not know the dynamics of lightning ignitions from the studied Jaksha area and this remains to be studied to understand better the pattern of large fire occurrence under natural conditions in the area.

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