Temporal History of Relationships between Scots Pine (*Pinus sylvestris* L.) Radial Growth and Mean Monthly Temperatures

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Abstract

The study on the temporal variation in relationships between the radial growth of Scots pine (*Pinus sylvestris* L.) stands and mean monthly temperatures was conducted using the radial growth parameters of three pine stands in Estonia and one stand in Russia. Stands were of various age and had different site conditions. The variability of the growth - temperature relationships was studied by computing and comparing the correlation coefficients between the radial growth and mean monthly temperatures from January to August for 30-year, 60-year and 100-year moving periods with a step of one year. The variability, expressed by variances in the time series of the correlation coefficients, is large and decreases significantly with the lengthening of the moving period. The analysis revealed pronounced trends in the correlation coefficients in all stands. The trends were ascending when average monthly temperatures of winter and summer months were used and predominantly descending in spring months. The values of the overall average correlation coefficients decrease, independing of stand age, with the lengthening of the periods. Although most relationships between the periodic correlation coefficients and the mean monthly temperatures of the same periods were statistically significant, the best correlations were generally obtained if average monthly temperatures of periods beginning 15–25(30) years ago were used.

Key words*:* Tree rings, Scots pine, temperature, variability, trends

Introduction

Trees integrate and record external environmental influences during their life-time. This record is stored in a visible and measurable form in the structure of tree-rings (Fritts 1976, Schweingruber 1996). The rings of trees provide a unique source of information on past variations in climate and other environmental factors which prevailed over a certain territory (Fritts *et al.* 1971). This information is often used in tree-ring analysis for modelling climate–growth relationships. These models can be used for predicting tree growth or for the reconstruction of past climate if the relationships are not changing over time (uniformitarian principle in dendroclimatology) (Fritts 1976, Van Deusen 1990).

In dendroclimatic investigations systematic changes in ring width associated with increasing tree age are removed by a standardisation procedure. The relationships between climate and standardised tree-ring indices are assumed to be independent of tree age (Fritts 1976). Trees pass several evolutional and age stages during their life. Each of these stages is characterised by a specific physiological response of trees to environmental conditions (Szeicz and MacDonald 1994). On the other hand, long- and short-term climate fluctuations exist and the basic distributional characteristics of the climate may change from one time period to the next. The increasing trends of air temperature and precipitation (Jaagus 1995), and noticeably a positive trend of the degree-days above 0 and 5ºC (Karing *et al.* 1999) were detected in the meteorological time series in Estonia. Therefore the assumption of a constant climate–growth response is very questionable even once the biological growth trend and the effect of prior growth have been removed (Pittock 1982, Van Deusen 1990).

Information on the details of the temporal variation of climate–growth relationships of trees of various age and in different time periods is scarce in earlier studies. Indirect indications on the variability or on the stability of the radial growth – climate relationships can be found in some dendroclimatological papers. Analysis carried out by Colenutt and Luckman at Larch Valley, Alberta (1991) revealed no significant differences between the responses of old (average age 303 years) and young (average age 81 years) *Larix lyalii* Parl. to climate during the life periods of the stands. No significant age effect on tree growth-climate response was detected for oaks in Fontainebleau, France (Gray *et al.* 1981). On the contrary, on the base of response function and regression analyses Szeicz and MacDonald (1994) found that the response of *Picea glauca* (Moench) Voss radial growth to climate varies between trees older than 200 years and trees younger than 200 years in northwestern Canada. It is assumed that a possible cause of the discrepancies between the responses of trees of various age to climate may be the differences in the physiological processes of older and younger trees, however (Gray 1982).

In the present report, results of the analysis on the temporal variability in the relationships between the radial growth of Scots pine (*Pinus sylvestris* L.) stands and temperature are presented. The aim was to study the relationships between the radial growth of different Scots pine stands and the mean monthly temperatures during various time periods. Though the exploration of the causes of the variability was not the aim of this study, an attempt was made to detect the dependence of these relationships on the average temperatures of the corresponding time periods.

Materials and methods

Study stands

The study was carried out in four Scots pine stands. Stands Tln1 (59º27'56'' N, 24º52'10'' E), Tln2 (59º27'57'' N, 24º 52'04'' E) and Tln3 (59º27'52'' N, 24º 52'01'' E) are located in northern Estonia. The annual mean temperature (1850–2006) and precipitation (1945–2006) were 4.9 C and 710 mm, respectively. The topography of the area is characterised by old postglacial sea dunes. Stand Bil (56º58' N, 59º48' E) is located on the eastern side of the Ural Mountains, about 60 km west from Yekaterinburg, Russia. The annual mean temperature and precipitation (1850–1989) in this area were 1.4º C and 430 mm, respectively.

Stands Tln1 and Tln2 are pure Scots pine stands and are defined according to the local site type classification as *Cladonia* site type (Lõhmus, 1984). The soil is nutrient poor fine-grained (0.1–0.25 mm) sand with low clay content. The organic layer is very thin and occurs sporadically. The shrub layer and ground vegetation are poorly developed. The age of stand Tln1 was approximately 270 years and that of Tln2 approximately 160 years. The increment samples were collected near the top and on the top of dunes for Tln1 and at the foot of the dune for Tln2. Stand Tln3 is defined as *Oxalis* site type. The soil is weakly podzolised sand on loam. The tree layer is composed of Scots pine with some Norway spruce (*Picea abies* (L.) Karst.). The shrub layer and field vegetation are well developed. The age of this stand was approximately 210 years. Stand Bil is defined by Estonian site type classification as *Rhodococcum* site type pine stand. The soil is a typical podzol with well-developed E horizon. The texture ranges from fine- to medium-grained sand. The tree layer consists exclusively of 160-year-old Scots pine. The shrub layer is poor and sparse as the ground vegetation is well developed.

Sampling and measurements

In the each stand 12–20 dominant or co-dominant trees were sampled for analysis of the radial growth. Lack of damage or defect was considered in sample tree selection. Each sample tree was cored at breast height on the southern and northern sides of the bole using a 4.3 mm increment corer. In laboratory each core, when dry, was mounted onto a grooved holder and the surface of the cores was cleaned and finished using sandpaper. The cores were crossdated with each other by regional pointer years to identify missing or false rings. The widths of tree rings on cores were measured to the nearest 0.01 mm with the Metronics tree-ring measuring system. Crossdating quality was assessed using the COFECHA program available in the Dendrochronology Program Library (DPL) version 2.1 (Cook *et al.* 1997). The trees with cores that were impossible to crossdate or poorly correlated with others were eliminated from further analysis.

Climate data

Monthly average temperatures from 1805 to 2003 collected in the Tallinn-Harku Meteorological Station of the Estonian Institute of Meteorological and Hydrology were used for the dendroclimatological analyses of stands Tln1, Tln2 and Tln3. The station Tallinn-Harku (59º23'54'' N; 24º36'15'' E) is located about 17 km southwest from the Tln study sites. Climate data for the period from 1760 to 1805 were obtained from Tarand (2003). Climate data for Bil stand are collected from the Sverdlovsk (Yekaterinburg) meteorological station (56°50' N, 60°38' E), the closest meteorological station to this stand. The distances of the meteorological stations from the studied stands are not large and the data from these stations can be considered as representative.

Statistical methods

Time series of ring-width measurements from individual trees generally contain long-term non-climatic fluctuations or trends, which are associated with increasing tree age. For investigation of the tree-ring–climate relationships this non-climatic signal must be removed from tree-ring time series using a procedure called *standardisation* (Fritts 1976, Cook *et al.* 1990). In this work, standardisation was accomplished with the ARSTAN program version 6.04P in DPL (Holmes 1994). The series of raw ring data were detrended with negative exponential or with 67 percent n-spline. The ARSTAN versions of the chronologies of tree-ring indices were computed for each stand. Along with the standardisation the mean sensitivity of the tree-ring index chronologies was computed.

The variability of the growth–temperature relationships was studied by computing and comparing the series of the correlation coefficients between the radial growth and monthly temperatures from January to August for moving 30-year periods with a step of one year. This procedure was repeated using 60-year and 100-year periods. The descriptive statistics and regression lines (trends) of the time series of the correlation coefficients of the successive periods were computed. The statistical significance of differences in variances in time series of the correlation coefficients for different moving periods was tested using Student's *t*-test.

To check whether the correlations between the radial growth and the mean monthly temperatures for the given period depend on the temperature of the same and/or previous period(s) the mean monthly temperatures were computed for each 30-year period. Then correlations between the series of the correlation coefficients and series of the mean monthly temperatures were computed. Further in the analysis the series of the correlation coefficients were set against the mean monthly temperatures of the preceding 30-year periods (like in autocorrelation computations). The procedure was repeated with lags from 1 to 30 years back. For stand Tln1 such analysis was made starting from years 1791, 1851 and 1901, for stands Tln2, Tln3 and Bil from 1861, 1802 and 1882, respectively.

Results

Ring-width chronologies

The ring-width index chronologies smoothed by the 5th order polynomial, display long-term growth fluctuations that may be related to the climate (Fig. 1). The periods of good and poor growth of trees have different duration in different stands and do not coincide precisely in time. However, in the case of stands Tln1, Tln2 and Tln3, if roughly generalised, the periods of good growth from 1850 to 1920 and from 1980 to the present may be distinguished. The radial growth was suppressed from 1800 to 1850 and from 1920 to 1980.

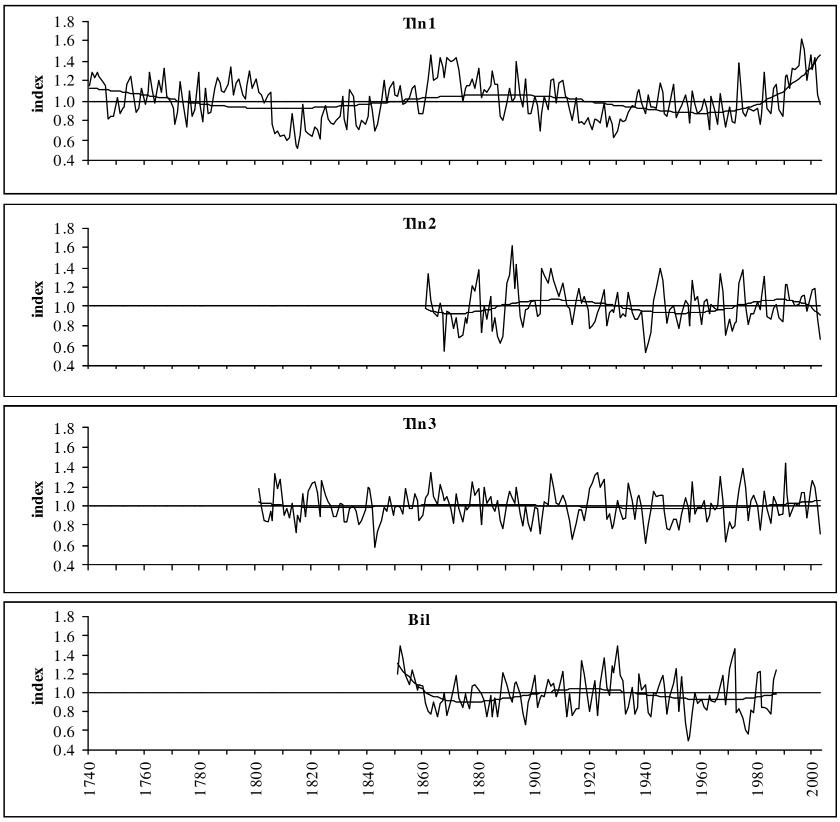

Figure 1. Radial growth (tree-ring indices) and smoothing curves (5th order polynomial) of Scots pine stands at sites Tln1, Tln2, Tln3 (Estonia) and Bil (Russia)

The chronology of stand Bil exhibits growth depression from 1860 to 1900 and from 1935 onward. The period of above average growth from 1900 to 1935 overlaps only slightly the period of good growth of the Estonian stands.

The results obtained by preliminary product-moment correlation analysis with full-length chronologies indicate that correlations between the radial growth of trees and monthly average temperatures were generally insignificant. Only the mean temperatures of the winter and early spring months were essential to the growth of trees in the Estonian stands. The pines growing on arid sites, such as stand Tln1 on the top of a dune, are considered to be more sensitive to moisture conditions. In the present study, the growth response to precipitation was lower than to temperature and insignificant in all stands.

It was observed that the mean sensitivity, which measures the relative difference in width from one ring to the next and exhibits the effect of limiting environmental factors on growth, is low in all standardised chronologies.

Table 1. Characteristics of the tree-ring width chronologies

Chronology statistics	Tln1	Tln2	Tln3	Bil
Time span	1761–2003	1861–2003	1802–2003	1852–1989
Length, years	243	143	202	139
Sample depth, trees	12	14	16	14
Average ring width, mm year^{-1}	0.75	1.22	1.25	1.20
First order autocorrelation of tree-ring widths	0.931	0.763	0.785	0.889
Standardised chronology				
Mean sensitivity of indices	0.145	0.162	0.149	0.167
Standard deviation of indices	0.207	0.194	0.158	0.210
First order autocorrelation in indices	0.642	0.432	0.347	0.483
Effective chronology signal	0.27	0.42	0.28	0.34
Variance, explained by temperature, %	8.7	32.0	25.8	15.5
Variance, explained by prior growth, %	49.7	20.1	16.7	20.5

Radial growth – temperature relationships

The dissimilarities between the correlation coefficients computed for successively shifted time periods of different duration suggest temporal instability in the relationships between the radial growth and climate. In many cases the correlation coefficients have noteworthy variability in successive periods and show clear trends during the investigated time interval.

Trends. The correlation coefficients between the radial growth and the mean monthly temperatures computed for the 30-year periods have an ascending trend (regression lines) in winter (January–March) and summer (July–August) months and a descending trend in spring months (April–June) in all stands (Fig. 2). In some cases (in April for stand Tln2, in July for stand Bil), the trends are rather ambiguous (the slopes are quite close to zero). Trends in the correlation coefficients for the 60-year and the 100-year periods are similar to those detected in the case of the 30-year periods for stands Tln1, Tln2 and Tln3. For stand Bil, if the 60-year periods are considered, the trends are descending in all months except January and especially August when clearly ascending trends are observed. Correlation coefficients computed for the 100-year periods show ascending trends also in February and July in this stand.

As the results show there are no essential differences in trends between Estonian stands depending on the age of stands and site conditions. The ascending trends in correlation coefficients in winter and early spring months follow the trends in monthly average temperatures of these months. The negative effect of the low temperatures during the winter and early spring months on the growth of pines in the following season in the Baltic region has been shown by several authors (Bitvinskas 1974, Shpalte 1978, Lõhmus 1992, Läänelaid and Eckstein 2003, Vitas 2004). Therefore the temperature in winter months may have a certain effect on the correlations between the radial growth and average monthly temperatures during this period. The slopes in trends in average monthly temperatures and slopes in trends in relationships between the radial growth and the average monthly temperatures in summer months were found to be low. Thus it is hard to detect clear relations between the trends in correlation coefficients and trends in average monthly temperatures in these months.

In stand Bil, growing in continental climatic conditions in the Middle-Urals, the trends in correlation coefficients differ from those detected in the Estonian stands, notably in the case of the correlation coefficients computed for the 60-year and the 100-year periods. The

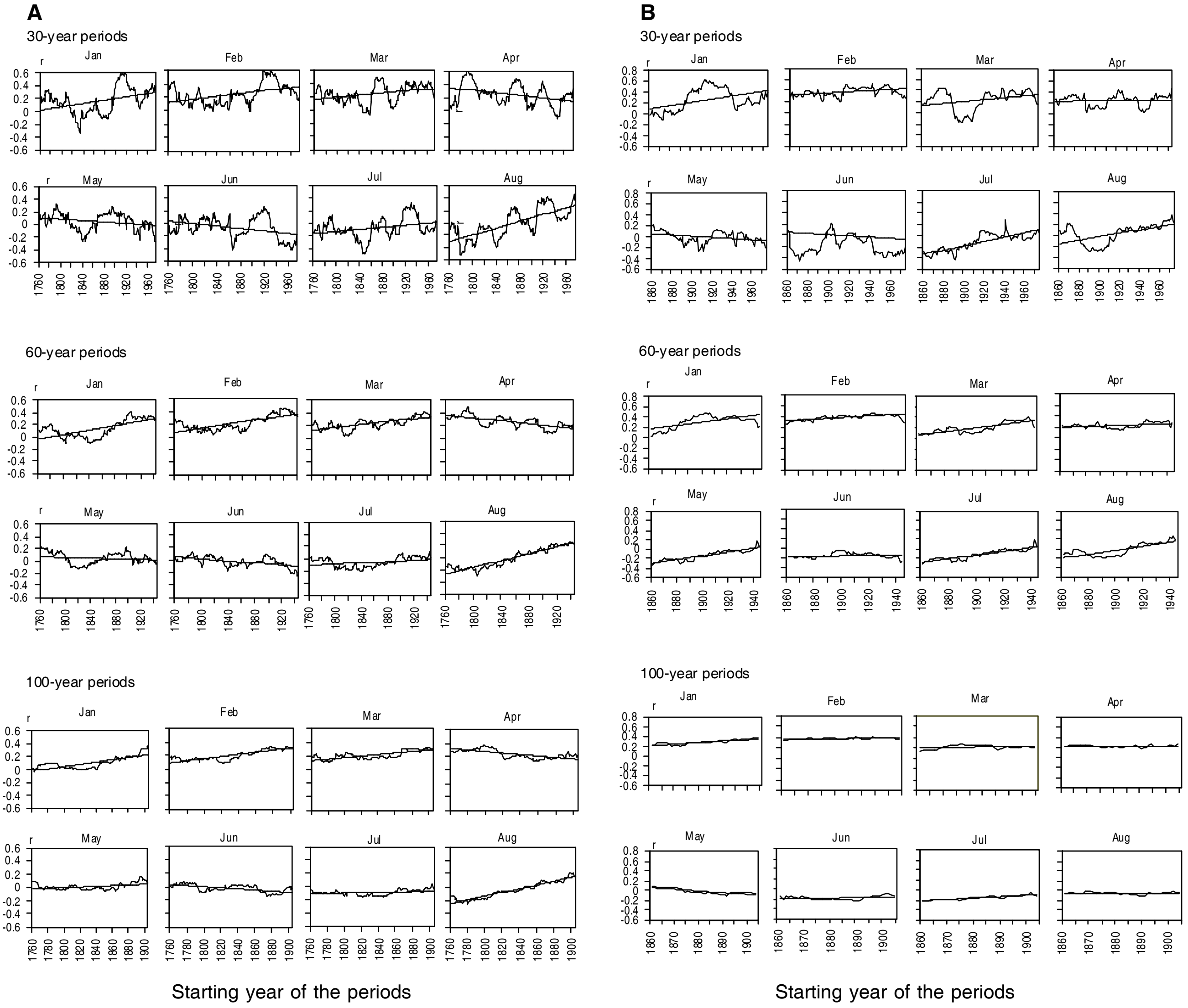

Figure 2. The variability of the correlation coefficients (*r*) between the radial growth and average monthly temperatures for the moving 30-year, 60-year and 100-year periods in stands Tln1 (A), Tln2 (B), Tln3 (C) and Bil (D). The correlation coefficient series are smoothed by fitting a linear regression

correlation coefficients between the radial growth of Scots pine and mean monthly temperatures computed for the period from 1850 to 1989 were statistically nonsignificant and very low. The mostly descending trends detected in the given case refer to the weakening of these long-term relationships in this region.

Monthly and average correlation coefficients for stands. Irrespective of the length of the moving periods the overall average correlation coefficients over all months are the highest for stand Tln3 and the lowest for stand Bil (Table 2). For months from January to April the average correlation coefficients are relatively high and positive in all stands though the periods characterised by negative values of the correlation coefficients can be observed on the graphs. For the next two months the values of the average correlation coefficients diminish rapidly and reach negative values in June. The relationships between the radial growth and the mean monthly temperatures for July and August become again stronger but generally do not reach the January–April level. As an exception, they reach this level in stand Bil.

A decrease in the values of overall average correlation coefficients along with the lengthening of the periods used for correlation computations was observed in all stands. No general regularity was detected, however, when the stand age was considered. The decrease was largest in the case of stands Tln1 and

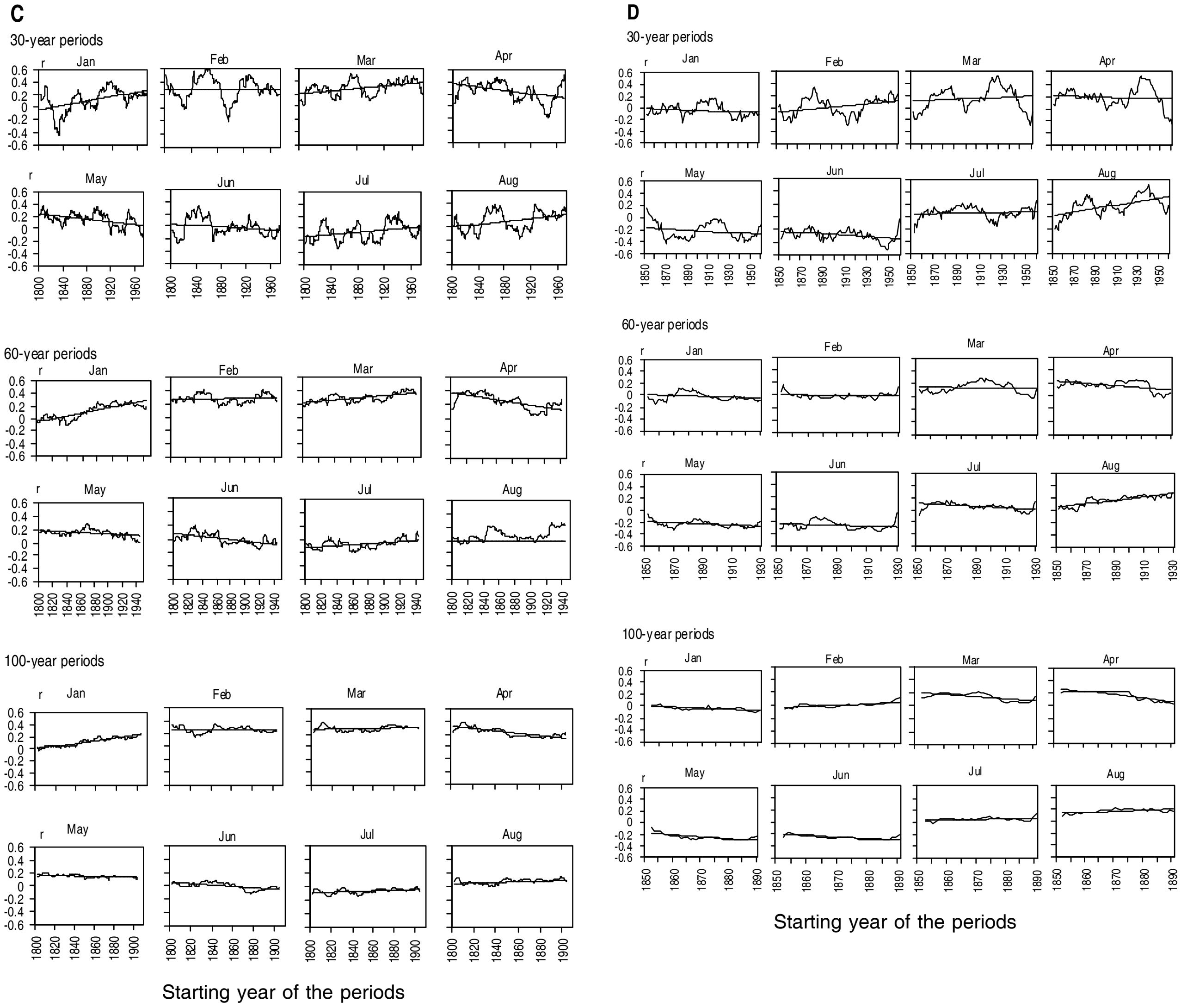

Figure 2. (continuing)

Tln2 growing on arid sites, on the top of a dune. The younger stand, Tln2, had lesser difference in the average correlation coefficients computed for 30-year and 100-year periods. In stand Bil the values of average correlation coefficients computed for different periods were close to zero and the variation was negligible.

When single months were considered some cases were detected when no essential variation in the average correlation coefficients depending on the length of the computation period was observed (*e.g.* in May for stand Tln3, in March and August for stand Bil) or they even increased along with the lengthening of the periods (*e.g.* in January and February for stand Tln2, in January for Tln3).

Variability. The variability in the correlation coefficients is noteworthy. The periods during which the correlation coefficients are positive may rapidly alternate with periods with correlations of negative value and *vice versa*. As a rule, variances decrease with the lengthening of the moving period. The variance was the highest when 30-year moving periods were used and the lowest in the case of the 100-year moving periods both in the time series of the monthly correlation coefficients and when the overall average variances are considered (Table 2). The differences in variances for different moving periods are statistically significant (two-tailed *t*-test, $p < 0.05$) in the case of all stands.

The variability in monthly correlation coefficients, expressed by variance, is different between Estonian and Russian (Bil) stands. In the first case the correlation coefficients exhibit the highest variability predominantly in January (Tln2 and Tln3) and August (Tln1)

Table 2. Statistics of the time series of the correlation coefficients between the radial growth and the average monthly temperatures computed for the 30-year, 60-year and 100-year moving periods, n – number of periods

Stands, periods Statistics	Month								Overall average
	January	February	March	April	May	June	July	August	
Tln1, 30 years (n = 214)									
Average	0.160	0.246	0.248	0.250	0.044	–0.066	–0.069	–0.010	0.1004
Variance	0.0433	0.0229	0.0193	0.0280	0.0181	0.0275	0.0275	0.0568	0.0304
Slope	0.0012	0.0011	0.0008	–0.0010	–0.0005	–0.0009	0.0008	0.0028	
Tln1, 60 years (n = 184)									
Average	0.134	0.226	0.225	0.253	0.048	–0.027	–0.060	–0.015	0.0980
Variance	0.0211	0.0137	0.0085	0.0090	0.0095	0.0070	0.0070	0.0246	0.0126
Slope	0.0018	0.0017	0.0012	–0.0012	–0.0003	–0.0009	0.0006	0.0028	
Tln1, 100 years (n = 144)									
Average	0.107	0.203	0.209	0.236	0.022	–0.023	–0.088	–0.044	0.0778
Variance	0.0090	0.0059	0.0039	0.0043	0.0023	0.0032	0.0018	0.0146	0.0056
Slope	0.0017	0.0015	0.0011	–0.0011	0.0005	–0.0008	0.0005	0.0028	
Tln2, 30 years (n = 114)									
Average	0.263	0.373	0.231	0.244	–0.014	–0.187	–0.116	0.034	0.1035
Variance	0.0454	0.0067	0.0337	0.0110	0.0107	0.0254	0.0234	0.0328	0.0236
Slope	0.0028	0.0009	0.0016	0.0002	–0.0010	–0.0007	0.0038	0.0032	
Tln2, 60 years (n = 84)									
Average	0.311	0.382	0.209	0.233	–0.010	–0.144	–0.126	–0.021	0.1043
Variance	0.0150	0.0028	0.0090	0.0021	0.0045	0.0033	0.0124	0.0176	0.0083
Slope	0.0032	0.0015	0.0032	0.0008	–0.0003	0.0003	0.0042	0.0042	
Tln2, 100 years (n = 44)									
Average	0.282	0.378	0.208	0.218	–0.022	–0.176	–0.151	–0.054	0.0854
Variance	0.0029	0.0029	0.0011	0.0003	0.0027	0.0014	0.0014	0.0006	0.0017
Slope	0.0036	0.0007	0.0005	–0.0002	–0.0032	0.0008	0.0026	–0.0001	
Tln3, 30 years (n = 173)									
Average	0.112	0.282	0.299	0.250	0.158	–0.016	–0.066	0.116	0.1419
Variance	0.0340	0.0320	0.0138	0.0279	0.0131	0.0212	0.0221	0.0260	0.0238
Slope	0.0018	0.0001	0.0010	–0.0015	–0.0011	–0.0007	0.0009	0.0012	
Tln3, 60 years (n = 143)									
Average	0.122	0.282	0.295	0.244	0.148	0.002	–0.062	0.083	0.1393
Variance	0.0137	0.0041	0.0042	0.0113	0.0028	0.0060	0.0048	0.0075	0.0068
Slope	0.0024	0.0001	0.0010	–0.0018	–0.0005	–0.0012	0.0008	0.0010	
Tln3, 100 years (n = 103)									
Average	0.126	0.266	0.297	0.231	0.151	–0.009	–0.075	0.063	0.1315
Variance	0.0062	0.0020	0.0016	0.0046	0.0009	0.0026	0.0014	0.0012	0.0026
Slope	0.0024	–0.0001	0.0003	–0.0018	–0.0006	–0.0011	0.0005	0.0005	
Bil, 30 years (n = 109)									
Average	–0.044	0.013	0.142	0.184	–0.226	–0.293	0.055	0.170	0.0001
Variance	0.0099	0.0220	0.0348	0.0264	0.0184	0.0081	0.0084	0.0238	0.0190
Slope	–0.0007	0.0015	0.0009	–0.0006	–0.0010	–0.0011	0.0003	0.0028	
Bil, 60 years (n = 79)									
Average	–0.022	–0.013	0.139	0.160	–0.226	–0.259	0.048	0.162	–0.0014
Variance	0.0046	0.0022	0.0069	0.0061	0.0026	0.0043	0.0029	0.0063	0.0045
Slope	–0.0007	–0.0002	–0.0003	–0.0016	–0.0008	–0.0006	–0.0012	0.0028	
Bil, 100 years (n = 39)									
Average	–0.039	0.004	0.138	0.174	–0.243	–0.250	0.045	0.167	–0.0005
Variance	0.0009	0.0015	0.0027	0.0052	0.0025	0.0011	0.0007	0.0012	0.0020
Slope	–0.0018	0.0025	–0.0030	–0.0054	–0.0032	–0.0021	0.0008	0.0020	

and the lowest in May. For stand Bil the highest variability was observed in March and April and the lowest in June.

Analysis of the variation of the correlation coefficients during the time interval common for all stands (from 1860 to 1960) revealed periods when the values of the correlation coefficients computed for both 30-year and 60-year moving periods tended to be above or below the regression line (or long-term average). In the case of stands Tln1, Tln2 and Tln3 the monthly correlation coefficients, except those in May, lie predominantly above the regression lines (or are larger than long-term averages) irrespective of the length of the moving periods, in 1915–1940. During the periods from 1890 to 1915 and from 1940 onwards the correlation coefficients lie mostly below the regression line. Such periodicity was not detected for stand Bil, however.

Examination of the temperature conditions in Estonia during these periods revealed that the average monthly temperatures of the winter months in 1915–1940 were lower and those of the summer months were higher than the corresponding average monthly temperatures during the previous and next periods. As shown above, cold winters do not favour the growth of pines in this region. It is expressed clearly by the lower average tree-ring indices (0.842) in 1915–1940 than in the preceding (1.021) and next (0.960) periods. Obviously the radial growth of pines was more sensitive to unfavourable growth conditions in the given case. Though the climate of the preceding growth seasons influences the tree growth in the current year (Fritts 1976), this effect on the radial growth was not studied in the given case during the above-mentioned three periods.

Relationships between correlation coefficients and mean monthly temperatures of the periods. The relationships between the periodic correlation coefficients and the mean monthly temperatures of the corresponding periods were computed to study if growth conditions, in this case the mean monthly temperatures of the corresponding periods, may have some effect on the growth/climate relationships expressed in this study as correlation coefficients. The biological background of such relationships needs further investigations, however. The obtained results differed largely between stands and months and depended on the length of the periods (Table 3). Not a single month was detected for which periodic mean temperatures were strongly interrelated with correlation coefficients for all moving periods and in the case of all stands. Although most correlations are statistically significant, really strong relationships between the correlation coefficients and the mean monthly temperatures of periods were not common. However, single cases of very strong relationships can be found. For example, the correlation coefficients of moving 100-year periods are highly and positively related to the corresponding periodic average January temperatures at stands Tln2 ($r = 0.84$, $p < 0.05$) and Tln3 ($r = 0.91$, $p < 0.05$) but negatively ($r = –0.76$, $p < 0.05$) at stand Bil.

Table 3. Correlations between the correlation coefficients of moving periods and the mean monthly temperatures of the corresponding periods

Stand	Period, years	Number of periods	January	February	March	April	May	June	July	August
Tln1	30	214	0.23	0.20	0.13*	–0.34	–0.16	–0.46	0.12*	–0.21
	60	184	0.40	0.52	0.64	–0.56	0.21	–0.34	0.61	–0.25
	100	144	0.63	0.77	0.74	–0.65	0.79	0.35	0.20	–0.53
Tln2	30	114	–0.32	–0.47	–0.09*	0.03*	–0.41	–0.51	0.53	0.60
	60	84	–0.49	–0.53	0.70	0.33	–0.15	–0.10*	0.35	0.61
	100	44	0.84	0.31	–0.01*	–0.03*	–0.86	0.32	0.57	–0.04*
Tln3	30	173	0.45	–0.21	0.10*	–0.41	–0.55	0.15	–0.01*	–0.04*
	60	143	0.50	0.46	0.64	–0.48	0.29	–0.41	0.76	0.10*
	100	103	0.91	–0.10*	0.28	–0.80	–0.46	–0.34	–0.01*	0.28
Bil	30	109	–0.07*	0.69	–0.41	–0.19*	–0.43	–0.29	–0.02*	0.41
	60	79	–0.21	–0.08*	–0.58	–0.43	–0.37	–0.28	–0.57	0.68
	100	39	–0.76	0.62	–0.74	–0.94	–0.76	–0.49	0.33	–0.26*

* non-significant at $p < 0.05$

In many occasions the absolute values of correlations tended to increase when longer moving periods were used. For example, for stands Tln1 and Tln3 the positive correlations between the correlation coefficients and the mean periodic temperatures of January were higher when the 60-year and the 100-year moving periods were used. For the same stands correlation coefficients were characterised by increasing negative values when the mean periodical temperatures of April were used in the analysis. Besides, in some occasions the highest or lowest correlations were computed using the moving 60-year periods. Such a situation can be observed in the case of stand Tln3, in which the correlations were the highest when the periodical temperatures of February, March and July were used.

Analysis of the correlations between the correlation coefficients computed for the 30-year periods and average monthly temperatures of the preceding 30-year periods with a lag of 1 to 30 years revealed different patterns in the variation of the relationships. Mostly the best correlations were obtained for the relationships between the correlation coefficients of periods and the average monthly temperatures of periods that began 15–25(30) years ago. In some cases strongest relationships were found with average monthly temperatures of the current or directly preceding periods. Changes of significant positive relationships to significant negative ones and vice versa during the retrospective 30 years were detected as well. In none of the stands essential variation in the relationships between the correlation coefficients of April and the corresponding monthly average temperatures of the previous 30-year periods were detected.

Analysis carried out for stand Tln1 and started in different time moments revealed that the detected variations in relationships between the correlation coefficients and average monthly temperatures of the previous periods are not stable in time, however. The lag in the first years of the 30-year periods at average temperature of which the correlations were highest varied considerably when analysis was performed from 1791, 1851 or from 1901 back. For example, when the analysis was started from 1791, highest relationships between the correlation coefficients and the average temperature in August were detected when the average monthly temperatures of periods at lags of 17–19 years were used. When started from 1851 or 1901, the highest correlation was observed for the average monthly temperature of the concurrent period. The underlying causes of such variation were not studied but need further examination.

Conclusions

The correlation coefficients between the radial growth of Scots pine and the mean monthly temperatures computed for successively shifted periods at a step of one year reveal pronounced trends in most cases. The trends are ascending when the average monthly temperatures of winter and summer months are used and predominantly descending in spring months. The variability in the correlation coefficients is great. Variances of the time series of the correlation coefficients decrease with the lengthening of the moving period. The trends and variation of the correlation coefficients differ to a certain extent in stands growing in geographically different regions. The values of the overall average correlation coefficients decrease, independing of stand age, with the lengthening of the periods used for correlation computations. Although most relationships between the periodic correlation coefficients and the mean monthly temperatures of the same periods are statistically significant, the best correlations are generally obtained when the average monthly temperatures of the periods that began 15–25(30) years ago are used.

The obtained results give once again evidence that there exists temporal variation in climate-growth relationships. The results show that the variation decreases when longer time periods are used in the analysis. The understanding of the variability in climate-growth relationships may be useful in modelling the forest growth when the climatological input consists of various climatic data recorded during different periods. This has essential importance at the present time, in the conditions of the global warming. The findings are relevant in the dendroclimatological investigations as well. For the effective use and interpretation of the variation in climate-growth relationships the knowledge of the factors determining this variability and underlying causal mechanisms is essential and therefore needs further research.

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ИЗМЕНЕНИЕ ВО ВРЕМЕНИ КОРРЕЛЯЦИОННЫХ СВЯЗЕЙ МЕЖДУ РАДИАЛЬНЫМ ПРИРОСТОМ СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.) И СРЕДНЕМЕСЯЧНЫМИ ТЕМПЕРАТУРАМИ

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Резюме

Коэффициенты корреляции между радиальным приростом (шириной годичных колец) сосны обыкновенной из различных географических районов и средних месячных температур вычислялись для последовательных периодов с шагом в один год. Анализ был проведен в периоды продолжительностью 30, 60 и 100 лет. В большинстве случаев были обнаружены заметные тренды в рядах коэффициентов корреляции. Тренды оказались поднимающимися, если в анализе использовались средние температуры зимних и летних месяцев, и падающими при случае применения температур весенних месяцев. Дисперсия в рядах коэффициентов корреляции уменьшается при использовании в анализе более длительных периодов. Тренды и изменчивость в рядах коэффициентов корреляции отличаются в древостоях, растущих в различных географических районах. Независимо от возраста древостоев среднее значение коэффициентов корреляции уменьшается при более длительных периодах.

В большинстве случаев корреляционные связи между рядами коэффициентов корреляции периодов и средними месячными температурами соответствующих периодов были статистически значимые. Однако более тесные связи были установлены, если в анализе использовали средние месячные температуры периодов начинающихся 15–25(30) лет тому назад вместо средних температур соответствующих периодов.

Ключевые слова: годичные кольца, сосна обыкновенная, температура, изменчивость, тренды