Response of Scots Pine (*Pinus sylvestris L.*) Radial Growth to Climate Factors in Estonia

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Abstract

The following research paper analyzes Scots pine (*Pinus sylvestris* L.) radial growth responses to climatic factors in mesotrophic and heath forest site types in Estonia. Increment cores from 889 trees from 119 plots of the network of research plots were used and chronologies for mesotrophic and heath forest site types of Scots pine were constructed. The relationship between climatic factors and the radial growth of Scots pine was characterized by correlation coefficient; also pointer year analysis, Cropper method was applied to single tree series. Cropper values were calculated; extreme negative and positive pointer years were identified. According to analyses, 1940 and 1985 were the most significant negative pointer years among different sites; and significant positive years were 1945, 1946, 1989, and 1990. Extreme Cropper values indicated significant positive correlation with the monthly mean temperature in winter (January, February) and early spring (March, April) before a growing season; also with the mean annual temperature and the mean temperature of the vegetation period (from April to September). Significant negative correlation was found between the extreme Cropper value and the precipitation of the previous year August. Therefore, temperature can be considered as the most important single factor of growth activity. Pointer year analyses confirmed that severe winters, cool springs and dry summer conditions are the main causes for the sharp decrease in the radial growth.

Key words: climate variables, pointer years, radial growth, Scots pine, tree-ring chronology

Introduction

The dynamics of the annual radial growth of a tree is closely related to fluctuations of climate and other ecological factors which encompass dendroclimatology (Fritts 1976, Cook and Kairiukstis 1990, Schweingruber 1996). Dendroclimatological methods are widely applied in modern studies on forest dynamics, assessing damages, forecasting climate changes, and productivity (Spiecker et al. 1996, Worbes 2004). Changes in average climatic conditions, such as air temperature, affect the length of the growing season and influence site productivity (Fabian and Menzel 1999). Tree rings are an excellent material for studying climate-growth relationships, as they reflect environmental conditions and changes, and store the reaction pattern over time, which can later serve as an archive (Spiecker 2002). Growth response to climatic influences varies with species, provenance, competitive status, and site conditions (Fitts 1976, Sweingruber 1996, Spiecker 2002).

Estonia became engaged in dendrochronological research in the early 1970s, with Kalvi Aluve (Läänelaid 1997, 2002) measuring and dating tree-ring widths in historical buildings, which was continued by Alar Läänelaid and Dieter Eckstein (2003), who constructed the long-term chronology for Scots pine (*Pinus sylvestris* L.), covering the period of 1516–1998 (482 years)**.** The use of radial tree-ring data in forest research was introduced in the 1980s, when Erich Lõhmus (1992a), a researcher at the Estonian Forest Institute, developed a generalized chronology for Scots pine in Estonia for the period of 1780–1983 (203 years). Lõhmus also compiled separate chronologies for three soil moisture classes (for arid, moderate, and humid sites), to enhance the sensitivity and informativeness of general chronology by minimizing typological diversity. Considerable input on studying the radial growth of Scots pine in park forests and regions of different cement dust loads has been provided by Henn Pärn (2003, 2004, 2006).

Scots pine is the species in which tree rings are one of the main sources of chronologies used in climate reconstruction (Lõhmus 1992a, Läänelaid 1997, Helama and Lindholm 2003, Vitas 2008) and have been used successfully in dendroclimatological research. It has the widest geographical distribution of all pines, and due to long rotation it is not problematic to find old trees that are considered suitable for dendrochronological studies. Different forces control its growth in climatically different regions (Cedro 2001, Helama and Lindholm 2003), any one of which may limit or stimulate their growth (Cedro 2001).

Scots pine is one of the most comprehensively investigated tree species in Estonia and Baltic countries by using dendroclimatological techniques (Vitas and Erlickytė 2007). In Estonia, pine is the most common and economically important tree species, with Scots pine dominating forests covering 29% (757,100 ha) of total forest area (MMK 2008). Therefore, due to the changing environmental conditions and evolving forest management objectives, updated information about trees and their growth is needed (Nilson 2002). For growth and yield studies in Estonia, the network of forest growth research plots (Kiviste and Hordo 2002) has been established since 1995. For modelling individual diameter growth, it would be necessary to consider the influence of climate factors on diameter increment during past decades by using chronological data (Mielikäinen 1985, Zahner 1988, Hynynen 1995, Gaucherela et al. 2008). Examining past relationships between tree growth and climate in Estonia will help us to understand how tree growth (productivity) in pine forests might be affected in the future.

The aim of our study is to analyze which season's climatic variables affect the annual growth of Scots pine the most, with particular attention to extreme climatic factors, like severe winters, cold springs and summer droughts, which can be the main causes for an abrupt decrease in the tree's radial growth.

Material and methods

Material collection

Increment cores from living Scots pine trees were collected in Estonia during the summer/autumn of 2007. For sample tree selection, we used growth and yield research plots established in mesotrophic and heath forest site types. Mesotrophic forests (*Rhodococcum* and *Myrtillus* site types) are dry and well-lighted pine stands, growing on moderately humid and temporarily moist sandy soils (Etverk et al. 1995, Lõhmus 2004). This forest type is the most widespread in Estonia, comprising 40.8% (MMK 2008) of pine dominated forest land. Heath forests (*Cladonia* and *Calluna* site types) are sparsely stocked pine stands, with slow growth, located on poor dry sandy soils. Heath forests can be found primarily in northern Estonia and on the islands and to a lesser extent in northeast, southeast and southwest Estonia. Heath forests are of great importance to coastal dunes where they provide soil protection. Heath forests comprise 1.5% (MMK 2008) of all pine dominated forests.

An Estonian network of forest growth research plots (Kiviste and Hordo 2002) similar to a Finnish INKA system (Gustavsen et al. 1988) has been designed to provide empirical data for forest growth and yield modelling (Kiviste et al. 2003, Hordo 2005, Kiviste et al. 2005). The network of 756 research plots with more than 100,000 mapped trees was established and re-measured in 1995–2007. For this study, a subset of 119 pine dominated sample plots was selected, which comprised 81 plots from the mesotrophic forest site type and 38 plots from the heath forest site type. According to the geographical location, the sample plots were grouped by regions: islands, northeast, southeast and southwest (Figure 1).

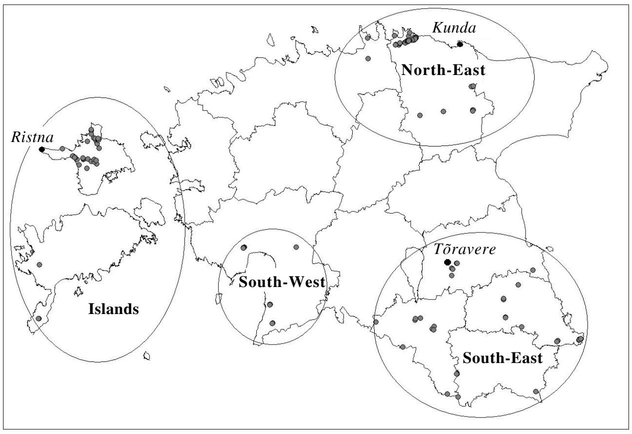

Figure 1. Layout of permanent sample plots, used for core collection and location of EMHI stations that provided metereological data

Increment cores were collected from trees outside the research plots from the North, South, East and West directions, which were determined from the center of a plot (Figure 2). For each research plot, up to 8 dominant trees without visible damages were sampled. Two increment cores in perpendicular radii were taken using an increment borer from each tree at 1.30 m above the ground. For this study, altogether 889 trees were cored from 119 sample plots, 602 trees from the mesotrophic and 287 trees from the heath forest site type.

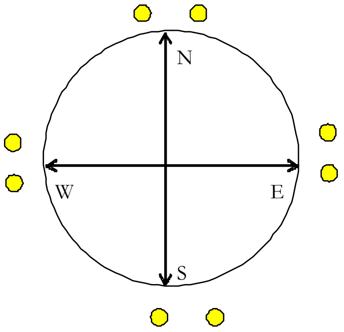

Figure 2. Location of sample trees (yellow spots) on the research plot. Sample trees of the research plot were taken from the basic compass points, outside the circular plot

Tree-ring measurements and cross-dating

Annual ring-widths were measured with an accuracy of 0.01 mm using LINTAB tree-ring measuring table with the computer program TSAP-Win Scientific Version 0.59 (Rinn 2003). The measured series were cross-dated (Pilcher 1990) visually by comparing the graphs of ring-widths. Cross-dating and data quality were assessed using the computer program COFECHA (Holmes 1983, Grissino-Mayer 2001). As a result of the cross-dating of tree ring time series, possible errors were eliminated and the series were verified among each other. Mean time series by trees and plots were built up with the software TSAP-Win.

Descriptive statistics of a ring-width series for mesotrophic and heath forest site types were calculated using the TSAP-Win program. Statistical paramaters of the tree ring data like mean sensitivity (*MS*), standard deviation (*Std*), tendency changes (*TC*), auto correlation (*AC*), Gleichläufigkeit (*Glk*), t-value (*TBP*), and Cross-Date Index (*CDI*) were calculated. The mean sensitivity (*MS*) is the mean percentage change from each measured yearly ring value to the next (Douglass 1936). Standard deviation (*Std*) is the measure of high-frequency variations (Fritts 1976). Tendency changes (*TC*) were calculated over the points of the running window, while creating a new time series and this new time series shows the variations of the calculated parameter along the original series (Rinn 2003). The first order autocorrelation *AR(1)* was calculated to estimate serial correlation (Fritts 1976).

To express the quality of accordance between time series, Gleichläufigkeit (*Glk*), Baillie-Pilcher value (*TBP*) (1973), and Cross-Date Index (*CDI*) were used. These parameters are characterized by different sensitivities to tree-ring patterns. Gleichläufigkeit (*Glk*) represents the overall accordance of two series, while Baillie-Pilcher value (*TBP*) presents the correlation significance, and Cross-Date Index (*CDI*) is the combination of these two parameters (*Glk* and *TBP*), which is a date index of possible series matches (Rinn 2003). Values of *Glk* greater than 60% and values of *TBP* greater than 3.0 and *CDI* = 10 were considered significant.

Standardization

Measured tree-ring series were standardized using the program ARSTAN (Cook 1985). All series were detrended using a negative exponential curve. Index values were calculated as ratios between the actual and fitted values. Index values were then prewhitened using an autoregressive model selected on the basis of the minimum Akaike (1974) criterion and combined across all series using biweight robust estimation of the mean to exclude the influence of the outliers (Cook 1985). As recommended by Henderson and Grissino-Mayer (2009), we used the residual chronology because it lowers the bias inherent in tree-ring indices and therefore, provides a more rigorous assessment of climatic influences. As a result of standardization, chronologies for the mesotrophic and the heath forest site type were compiled.

As a reference chronology, we used the chronology for Scots pine compiled by Erich Lõhmus (1992a). For his chronology, Erich Lõhmus used the detrending method of the moving average of 21 years.

Climate data

Sums of monthly precipitation (mm) and air temperature means (ºC) were obtained from Kunda (for North-East, location 59°31’05”N 26°32’44”E; period 1919–2007), Ristna (for islands and South-West, location 58°55’14”N 22°04’02”E; period 1945–2007) and Tõravere (for South-East, location 58°15’50”N 26°27’42”E; period 1866–2007) stations of the Estonian Meteorological and Hydrological Institute (EMHI). To illustrate climate data, average monthly temperatures, the mean temperature of the vegetation period (from April to September) and mean annual temperatures as well as monthly sums of precipitation, the sum of precipitation in the vegetation period and the annual sum of precipitation were calculated over the periods (Figure 3).

In general, Estonia has a temperate climate, with warm summers and severe winters. The average annual temperature is 4–6 °C. The annual sum of precipitation is between 500 mm and 750 mm, about 40–80 mm of which falls down as snow. The active period of vegetation growth (daily air temperature above 5ºC) mostly lasts between 170 and 180 days per year.

Analysis of climate-tree growth relationships

Relationships between climate variables and the tree radial increment were evaluated using the pointer year analysis and correlations. The pointer year analysis is an accepted method of showing annual growth reactions due to abrupt changes in environmental conditions (Cropper 1979, Schweingruber 1990), especially those due to climate variations (Rolland 1993, Kroupova 2002, Neuwirth et al. 2004, Karpavičius and Vitas 2006, Elferts 2007). To calculate pointer years, we used Cropper (1979) method, where ratios among the raw annual measurements for single tree series and their 13-year moving average were calculated:

$$Z_i = \frac{x_i - mean[window]}{stdev[window]}$$

where: x_i – tree-ring width in year i; *mean*[*window*] and *stdev*[*window*] – arithmetic mean and standard deviation of ring widths in the moving window x_{i-6}, x_{i-5}, x_{i-4}, x_{i-3} x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2}, x_{i+3}, x_{i+4}, x_{i+5}, x_{i+6}. Years with a

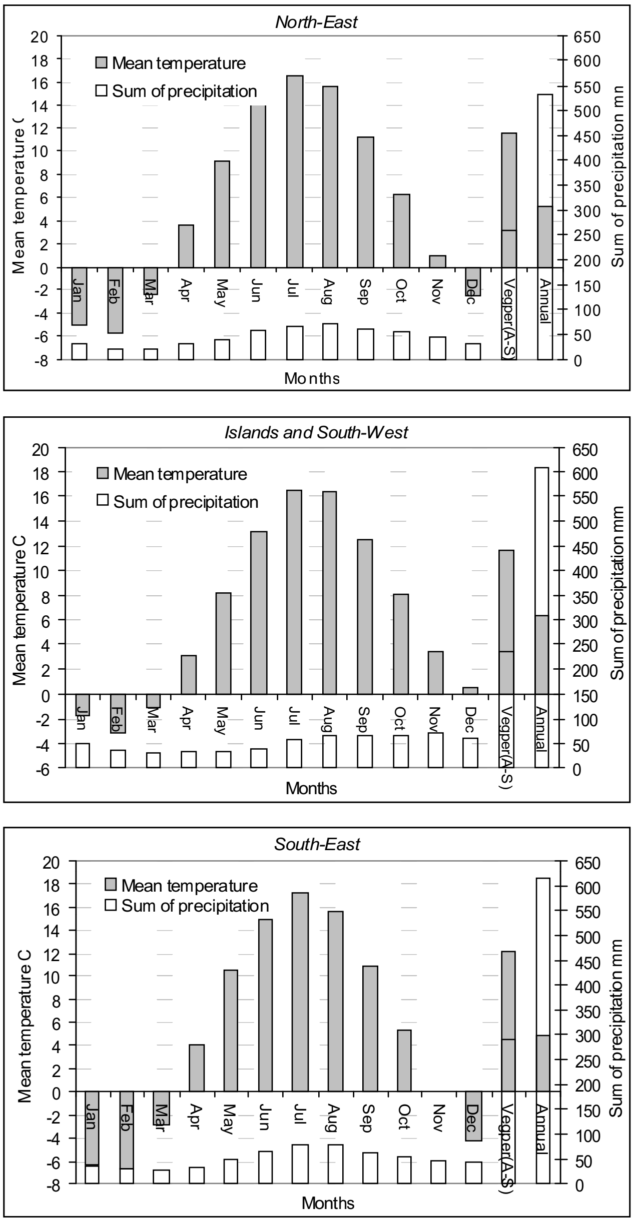

Figure 3. Mean monthly temperatures and sums of precipitation averages from Kunda (period 1919–2007), Ristna (period 1945–2007), and Tõravere (period 1866–2007) weather stations of EMHI

value of Z_i that was higher or lower than 1 or -1 (Neuwirth et al. 2007, Pourtahmasi et al. 2007) were defined as positive or negative pointer years, respectively. Those positive and negative Cropper values were divided into three classes by intensity: 'weak' for $|Z_i|>1$, 'strong' for $|Z_i|>1.28$ and 'extreme' for $|Z_i|>1.645$ (Neuwirth et al. 2007).

Pearson's correlation coefficient between Cropper values Z_i and climate variables (the mean temperature and the sum of precipitation) for both forest site types by regions was calculated and the t-test for the comparison of the means of climate data between normal years and strong/extreme pointer years was performed using SAS software (SAS 1996).

Results and discussion

Tree-ring chronologies

While building up the general dendrochronology it is important to retain growth fluctuations by climate factors within the chronology when larger areas are being summarized, with different growing conditions. In this study, 889 trees from 119 plots were sampled from the Estonian network of forest growth and yield research plots and separate chronologies were built for mesotrophic and heath forest site types (Figure 4) for different regions of Estonia (Figure 5, Figure 6). The chronology for the mesotrophic forest site type is 145 years long, and based on 602 trees, covering the period 1796–2007; whereas the chronology for the heath forest site type is 221 years long and based on 287 trees, covering the years from 1786 to 2007.

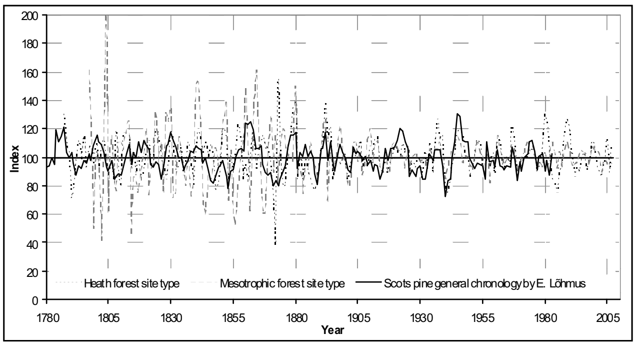

Figure 4. Indexed chronologies of Scots pine for heath and mesotrophic forest types and the reference chronology by Lõhmus (1992a)

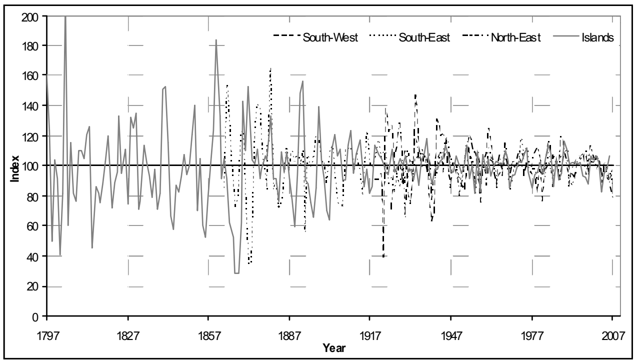

Figure 5. Dendrochronological series for mesotrophic forest types of Scots pine by regions

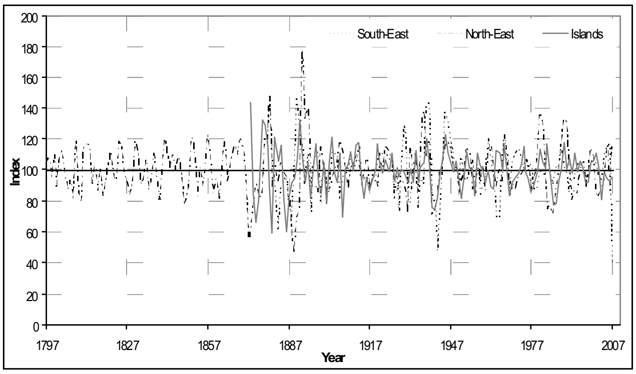

Figure 6. Dendrochronological series for heath forest types of Scots pine by regions

Updated chronologies were compared to the reference chronology built by Lõhmus (1992a) and measures of accordance were calculated (Table 1). *Glk* between the mesotrophic forest type and the reference chronology ranged from 56.1 to 77.2%, and between the heath forest type and the reference chronology varied from 72.8 to 80.7%. In South-West region, *Glk* was not significant. The *TBP* showed significant conformity between new chronologies and then the reference chronology, 7.1 for the mesotrophic and 5.0 for the heath forest type. Consequently, the overall conformity between new and reference chronologies was statistically significant. Intercorrelation among regional chronologies within a forest site type was statistically significant ($p < 0.05$).

Descriptive statistics for indexed tree-ring series were calculated. The mean sensitivity varied between 8 and 14% (Table 1), whereas the values for mesotrophic forests were lower than those for heath forests, which shows that heath forests are more sensitive to climatic factors. The low first-order autocorrelations indicate that the influence of climate on the inter-annual growth variability of pine is high (Wigley et al. 1984, Pourtahmasi et al. 2007). We found out that ring width growth was mostly influenced by the previous year weather conditions, in the heath forest site type in South-East (*AR(1)* = 0.78). At the same time, a low influence of the previous year was detected in North-East (the mesotrophic forest site type) and islands (the heath forest site type), with *AR(1)* = 0.45. All these findings above confirm that the pine chronologies from our network of sample plot data are suitable for studying the effects of climate on the radial growth.

Correlation analysis

The results of correlation analyses between the radial growth indices and climate data, which include monthly temperatures and precipitation from the previous growing season to this year, are presented in Figure 7. On both forest sites, correlation analyses revealed that tree-width growth is positively correlated with winters prior to the growing season temperature and the temperature during the vegetation period. Additionally, tree growth is significantly negatively correlated with the previous year August temperature and positively correlated with sum of the precipitation of this month. This indicates that high temperature and low amount of precipitation at that time is limiting the increment growth of pine. The analysis showed that in southwest Estonia in mesotrophic forest site types, precipitation in February has a significant positive influence on the radial growth. Considering that February is one of the coldest months in Estonia, with the average temperature from –3.3 to –7.4°C, higher

Table 1. Internal statistical properties of time series of Scots pine forest types by regions (generalized chronology by Lõhmus was compared to sample plots chronologies). *Std* = standard deviaton; *AR* = first-order autocorrelation (lag = 1); *MS* = mean sensitivity; *TC* = tendency changes; *Glk* = Gleichläufigkeit; *TBP* = T-value with Baillie-Pilcher-Standardization; *CDI* = Cross Date Index; * 95% significance for the *Glk* value

Forest type	Region	No. of stands	Length of series	Ring widths index							Glk%	TBP	CDI
				Min	Mean	Max	Std	AR(1)	MS %	TC %			
Heath	General	37	221	64	99	150	16.5	0.67	11	48	78.1*	5.0	30
	South-East	3	129	58	101	197	27.0	0.78	14	64	72.8*	4.9	32
	North-East	27	221	63	98	161	19.1	0.66	13	47	73.7*	4.5	24
	Islands	7	135	74	100	129	11.6	0.43	10	59	80.7*	06.Bir	44
Mesotrophic	General	72	211	78	101	126	8.1	0.64	8	69	75.4*	01.Lie	41
	South-East	25	145	74	100	145	12.5	0.63	8	69	76.3*	7.9	44
	North-East	13	83	67	100	125	11.7	0.41	10	62	72.8*	3.7	25
	Islands	23	210	76	101	128	11.1	0.45	9	58	77.2*	6.0	38
	South-West	11	89	63	101	133	14.1	0.53	10	48	56.1	3.4	8

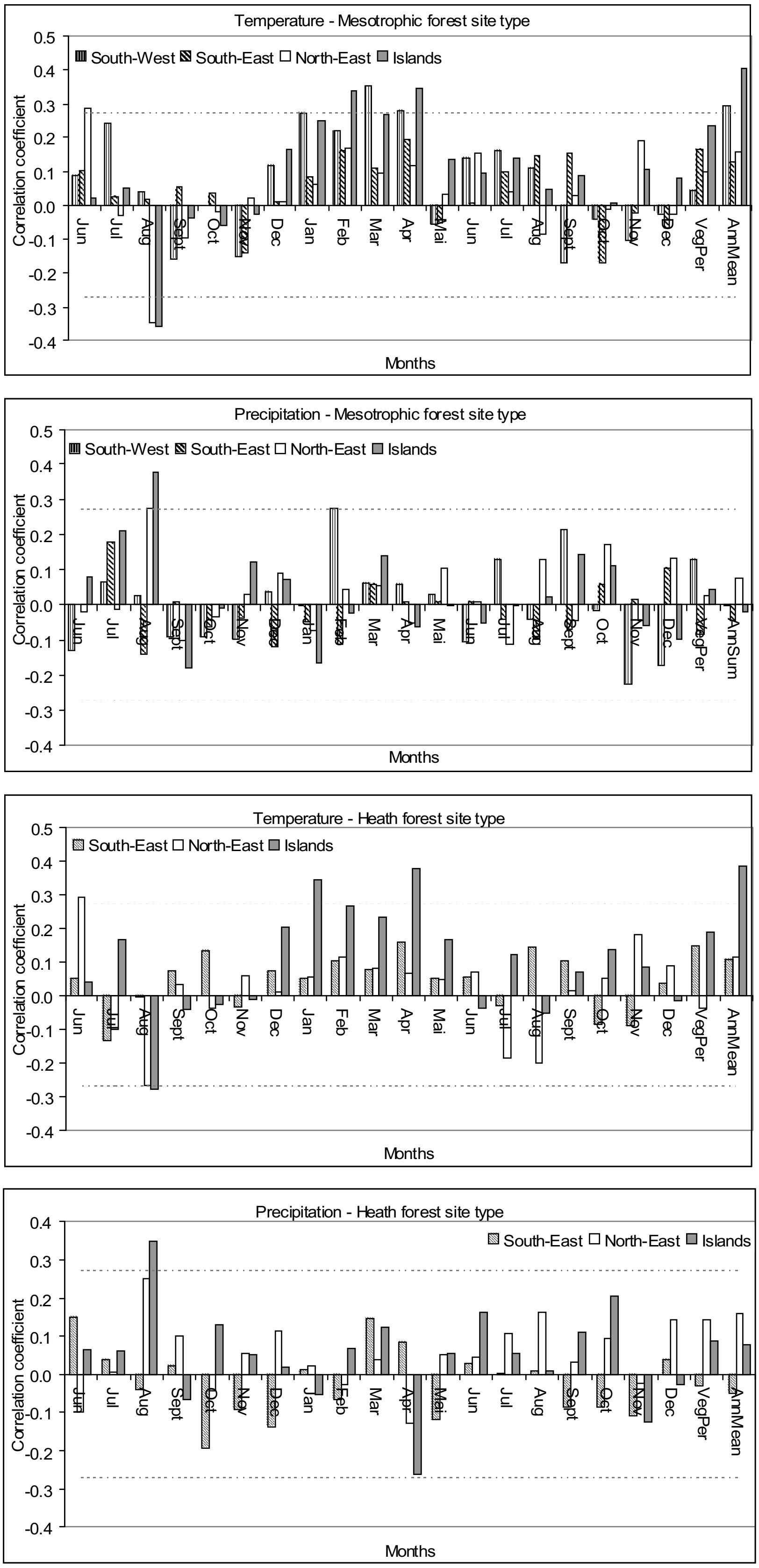

Figure 7. Correlation coefficients for Scots pine chronologies (mesotrophic and heath forest site types) between ring-width indices and total precipitation and the mean monthly temperature. Dashed lines mark the significant level (r = 0.273 or r = –0.273) at p = 0.05

amount of precipitation (snow) would stimulate tree growth in spring. On the islands, precipitation in April has a significant negative impact on the radial increment. The annual mean temperature is significantly positively correlated with tree-ring indices of pine on both sites. All the findings above suggest that the mean annual temperature significantly depends on winter climate, and when severe winter was followed by a long and cool spring, such factors limit tree growth.

Pointer year analysis

The Cropper values were calculated from single tree curves for mesotrophic and heath forest sites in different regions as growing conditions varied. Extreme negative and positive pointer years were identified when the Cropper value was lower than –1.645 or higher than 1.645 and strong pointer years were below –1.28 and above 1.28, respectively. On mesotrophic forest sites significant extreme negative pointer years of 1929 and 1940 in the southwest region were detected and 1934, a positive year; in the southeast region, an extreme negative pointer year was 1940 and a positive event year was 1945; in the northeast region, considerably negative pointer years were 1937 and 1985 and there were no significant positive years; on islands, significant negative years were 1901, 1940, 1985 and the extreme positive pointer year was 1989. On heath forest sites significant negative extreme years were detected – 1906, 1931, 1932 and 1942 in the southeast region, and positive years were 1921, 1923, 1945, 1946, 1988, and 1997; in the northeast region, important positive extreme years were 1921, 1967, 1980, 1981, 1989, 1990 and negative years were 1920, 1940, 1941 and 1985; on islands, significant positive years were 1910, 1938, 1945 and negative years were 1940, 1941, and 1956.

The results of the pointer year analysis are presented in Table 2. The analysis of pointer years identified 19 positive and 19 negative years on mesotrophic forest site types, and 34 positive and 27 negative years on heath forest site types. According to analyses, 1940 and 1985 were the most significant negative years. The records of EMHI prove that the most severe winters over the past century were in 1939/40, 1940/41, 1941/42 and cold winters were in 1984/85, 1986/87, 1995/96. This indicates that the cold winter prior to the growing season and late spring (mean T Mar–May +2.4ºC) affected the radial increment of pine tree growth and it was the main cause of the sharp decrease in the radial growth. Similar results were obtained in Estonia by Läänelaid and Eckstein (2003) and in Lithuania by Vitas (2008). Extreme events usually last only a few months and the organism can survive these conditions

Table 2. Negative (–) and positive (+) pointer years $|Z_i|>1.28$ of the radial growth of Scots pine by regions (extreme event years $|Z_i|>1.645$ are highlighted)

Year / Region	Heath			Mesotrophic			
	South-East	North-East	Islands	South-East	North-East	Islands	South-West
1901						**-**	
1902		-	+				
1903			+				
1906	**-**						
1907		+					
1909	-						
1910			**+**				
1911	+						
1913	+		+				
1914	-						
1918	+						
1919		-					
1920		**-**					
1921	**+**	**+**					
1922	+						
1923	**+**						
1925			+				+
1927							
1928	-				+		
1929							**-**
1931	**-**	-					
1932	**-**			-	+		-
1934		+					**+**
1936					-		
1937		+			**-**		
1938	-		**+**			+	
1940		**-**	**-**	**-**		**-**	**-**
1941		**-**	**-**				
1942	**-**						
1945	**+**	+	**+**	**+**			
1946	**+**	+	+	+			
1948	+						
1951			-				
1953							
1956			**-**	-			
1957					+		
1958	-					-	
1961	+						
1962					+		
1967		**+**					
1969		-	-		-	-	
1970	-						
1973					+		
1975				+			
1977			-			-	
1980		**+**	+		+	+	
1981		**+**		-			-
1983		-	+				+
1984	+	-			-		
1985		**-**			**-**	**-**	
1986			-				
1988	**+**						
1989		**+**			+	**+**	
1990		**+**			+	+	
1991	-						
1997	**+**						
1999					+		
2001		-					

(Ahas et al. 2000), but the influence of extreme events may last for several years (Jaagus et al. 2003). The winter severity determines directly when the spring begins. In most cases, a severe winter is followed by a late, cool spring and an early and warm spring followed by a mild winter (Jaagus et al. 2003). The pointer year analysis revealed that significant positive pointer years were 1945, 1946, 1989 and 1990. According to the EMHI, warm winters appeared in 1945 (mean T Dec-Feb –3.9ºC), 1946 (mean T Dec-Feb –6.4ºC), 1988/89 (mean T Dec–Feb –1.0ºC) and 1999/2000 (mean T Dec–Feb –1.7ºC). Even though in 1946 the average winter temperature was below average (long period mean T –5.6ºC), it seems that the warm winter of the previous year had a positive effect on increment growth.

Additionally, growth-climate relationships were tested with the correlation of strong/extreme Cropper values and climate data. The results of the analysis are presented in Figure 8. The results indicate a positive correlation of Cropper value with the mean temperature in winter, particularly in January and February, and with the temperature in the beginning of the growing season (March, April). However, no negative correlation with average winter temperatures was found, but in an earlier study, Lõhmus (1992b) detected a high negative correlation of the radial growth with winter minimum temperature. A statistically significant positive correlation with temperatures in June and July was detected on the mesotrophic forest site type, while the temperature was significant for growth on heath forest site types in September and October. Scots pine showed a statistically significant positive response to the mean annual temperature and the temperature of the growing season. Analysis revealed that the high temperature of the previous year August had a negative effect on the radial growth, but the precipitation in this month had a positive influence on the radial increment. This negative effect of the temperature on the radial growth could be explained by the promotion of bud differentiation during this time. The late summer temperature affects the amount of nutrient storage which encourages sprouting in spring. This in turn affects the next growing year ratio of sprouts and diameter increment (Lõhmus 1992b). A similar effect is mentioned in Finland by Henttonen (1984) and in Sweden by Jonnson (Lõhmus 1992b). In mesotrophic forest site types, annual precipitation had a negative impact, while on heath forest site types, the sum of precipitation was important during the vegetation period. The results of the analysis showed that the impact of precipitation on the radial growth of trees in comparison to temperatures was not so significant. Temperature may be considered as the most important single factor initiating growth activity (Vaganov et al. 2006); however, low humidity can cause an earlier termination of growth in a season (Fritts 1976), in our case on heath forest site types. A combination of temperature and humidity changes in particular intervals of a season produces acceleration or deceleration of growth processes (Schweingruber 1996). It is confirmed by Jaagus et al. (2003, 2006) that beside temperature, precipitation has the most profound effect on the

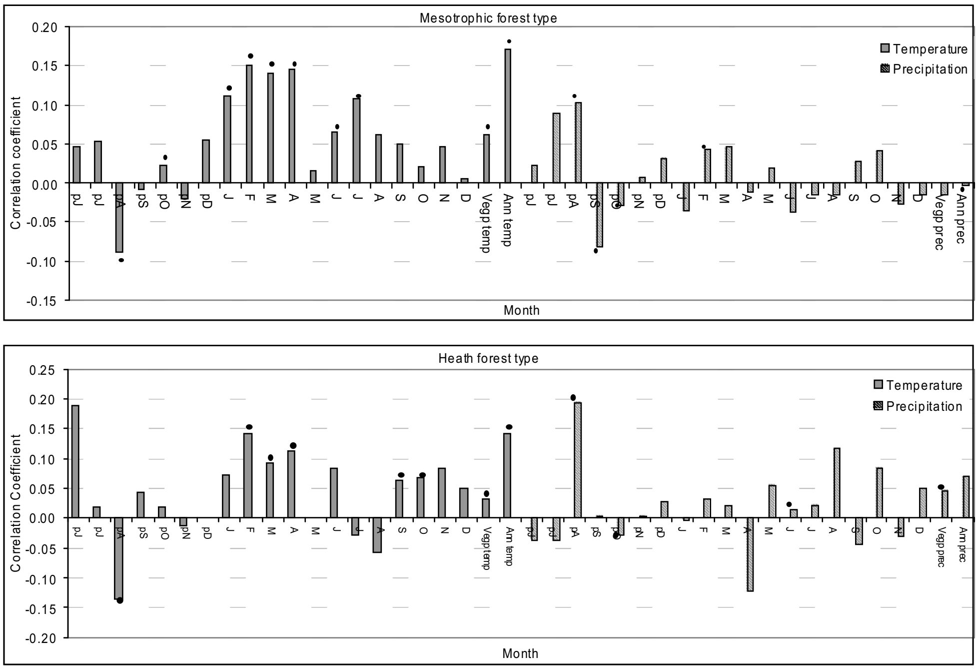

Figure 8. Correlation between monthly and seasonal climate data (temperature and precipitation) and Cropper-values in heath and mesotrophic forest sites; responses were similar in all regions. • indicates statistical significance (p<0.05)

growth; however, precipitation is an extremely unstable climate variable which makes long-term changes almost impossible to predict.

Finally, we used the t-test on climate data to analyze the differences between normal years and strong/ extreme years. The results of the test confirmed our previous results that positive and negative pointer year had a significant effect on the mean annual temperature and the temperature of the growing season, as well as on the temperature and the sum of precipitation in August of the previous year. This means that extreme climate events are influencing the radial increment growth of pine trees.

Conclusions

In this study we compiled new chronologies for mesotrophic and heath sites for Scots pine and analyzed the responses of the radial increment to climatic factors. Measures of conformity *Glk* between the mesotrophic forest type and the reference chronology ranged from 56.1 to 77.2% and between the heath forest type and the reference chronology varied from 72.8 to 80.7%. Therefore, the overall conformity between new and reference chronologies was statistically significant ($p < 0.05$).

The results of correlation analyses between radial growth indices and climate data, on both forest sites revealed that tree-width growth is positively correlated with temperatures in winter time and prior growing season, and temperatures during growth season ($r = 0.273$; $p > 0.05$). This means that the mean annual temperature significantly depends on winter climate, and when severe winter was followed by a long and cool spring, such factors limited tree growth.

The pointer year analysis identified 19 positive and 19 negative years on mesotrophic forest site types, and 34 positive and 27 negative event years on heath forest site types. The analysis revealed that 1940 and 1985 were the most significant negative years, while significant positive pointer years were 1945, 1946, 1989 and 1990. Additionally, growth-climate relationships from the correlation analysis revealed the statistically most significant positive response to the mean annual temperature and the temperature of growing season ($p < 0.05$) in both forest site types, while the monthly consequence of the correlation varied.

Acknowledgements

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ВЛИЯНИЕ КЛИМАТИЕСКИХ ФАКТОРОВ НА РАДИАЛЬНЫЙ ПРИРОСТ СОСНЫ ОБЫКНОВЕННОЙ *(PINUS SYLVESTRIS L.)* В ЭСТОНИИ

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Резюме

В данной статье анализируется влияние климатических факторов на радиальный прирост сосны обыкновенной (*Pinus sylvestris* L.) в мезотрофных и верещатниковых лесах Эстонии. Хронология сосны обыкновенной, растущей в мезотрофных и верещатниковых лесах, была составлена на основании анализа годичных колец 889 деревьев, полученных в сети 119 пробных участков. Отношения между климатичекими факторами и радиальным приростом были оценены, используя коэффициент корреляции Пирсона, а также при помощи анализа реперных лет. Единичные деревья были оценены при помощи метода Кроппера. Согласно результатам анализа, 1940 и 1985 были негативными реперными годами, тогда как 1945, 1946, 1989 и 1990 позитивными. Эта тенденция сохраняется для изученных мест произростания. Экстремальные значения Кроппера имеют позитивную корреляцию со средней месячной температурой зимой и ранней весной. Негативная корреляция наблюдается с количеством осадков в августе прошлого года. Температура является наиболее важным фактором, влиющем на интенсивность радиального прироста. Анализ реперных лет подтвердил, что суровая зима, поздняя весна, а также сухое лето, являются основными причинами резкого сокращения радиального прироста.

Ключевые слова: радиальный рост, климат, реперный год, сосна обыкновенная, хронология годичных колец