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INFLUENCE OF CLIMATIC FACTORS ON THE ANNUAL RADIAL GROWTH OF SCOTS PINE (*Pinus sylvestris* L.) IN WESTERN LATVIA

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*Dendroclimatological research has been perfomed in Latvia after a break of about 25 years. The growth pattern of Scots pine (*Pinus sylvestris *L.) in six districts of western Latvia is analysed in relation to climatic factors (monthly and seasonal mean air temperature and precipitation). Applying various statistical techniques, it was observed that in this area the growth of pine on mineral soils with normal moisture conditions has been affected most significantly by the mean air temperature during the period from the second half of January to the first half of April of the same year. Thus, the period when mean air temperature is the most significant influence is similar across an area at least from Lithuania (inclusive) to southern Scandinavia, while further north it is mean summer air temperature that gradually becomes the determining factor in the radial growth of pine. Also the quality of the dendrochronological signal in tree-ring chronologies of pine growing in the environmental conditions of Latvia was determined and signature years during the 20th century were identified, when the majority of pines throughout the territory of the Baltic States exhibit a similar change in annual radial growth.*

Key words: Pinus sylvestris*, dendroclimatology, dendrochronological signal.*

INTRODUCTION

The influence of climatic factors on the annual radial growth of trees in Latvia has been studied previously. This work began in the late 1940s and continued, with minor interruptions, until the mid-1980s. The main contribution was made by the Latvian forest researchers A. Zviedris (Zviedris, 1950; Zviedris and Sacenieks, 1958; Звиедрис и Сацениекс, 1960) and E. Špalte (Špalte, 1975a; 1975b; Шпалте, 1978). The influence of particular meteorological factors on the radial growth of tree stems in Latvia has also been studied, to a lesser degree and with other aims, in the frame of research by several other forestry specialists—P. Zālītis, P. Skudra, I. Liepa, J. Jātnieks, and others (Залитис, 1967; Zālītis un Šitca, 1986; Liepa, 1972; Лиепа, 1980, pp. 107–112; Скудра, 1982; Jātnieks, 1991). This work, which can be equated to dendroclimatological research, was undertaken mainly in the period when the possibilities of large-scale data processing were still very limited, compared with the present day. At that time, the main research aim was usually to establish the influence of climatic factors on the annual growth of the economically most important tree species, in order to be able to assess more objectively the effectiveness of forestry practices in increasing the total wood volume. It must be admitted that in the majority of cases the studies were limited to particular areas of Latvia or even to particular forest stands, or to one particular forest site type, which means that the results obtained were mostly of local importance.

During the past 25 years, several studies in dendroecology have been undertaken in Latvia, and during the past 15 years dendrochronology has also been studied (in the more restricted sense of the two terms), while research relating to dendroclimatology has practically ceased. On the other hand, in many other countries of Europe and elsewhere in the world, this period has seen major breakthroughs in this particular sub-field of research.

When we compare the results of previous dendroclimatological studies undertaken in Latvia with those obtained in other European countries, including Lithuania, we see that the research undertaken so far in Latvia has not provided answers to many important questions, for example:

a. Why have the conclusions drawn so far in Latvia as to the importance of the influence of climatic factors on tree growth differed so markedly?

b. Can the influence of climatic factors on the radial growth of trees in the environmental conditions of Latvia really be considered unimportant? How can this be explained?

c. What is the quality of the dendrochronological signal in the territory of Latvia? How has it changed from year to year?

d. How does the influence of climatic factors on tree development in the territory of Latvia change during particular periods of the year and in relation to the geographical position of the forest stands and site conditions? How does this influence change, when we compare the territories of all three Baltic States?

e. How does the influence of climatic factors on the growth of different tree species vary in the environmental conditions of Latvia?

f. How does global warming influence the development of trees growing in the territory of Latvia?

g. Can the tree-ring series obtained in Latvia be applied in order to reconstruct past local climatic parameters and forecast climatic change in the future, and if so, then how?

In order to answer these and related questions, it is necessary to undertake comprehensive dendroclimatological studies in Latvia, studies that should cover the whole country. In 2005, research aimed at attaining this aim was started at the University of Latvia.

The goal of the work was to first determine the influence of climatic factors on the annual radial increment of pine in the most northerly, easterly, southerly and westerly parts of the territory of Latvia, and in forest stands located exactly between these furthest outlying areas (Fig. 1). It was planned that north–south variation in the influence of climatic factors would first be determined for western Latvia and then for eastern Latvia. Presented in this paper are the results of initial dendroclimatological research undertaken in western Latvia. These results already provide partial answers to the questions set out in the first four points (a – d) of the above list.

MATERIALS AND METHODS

Collection of wood samples. Samples of pine wood were collected at the following locations in western Latvia: in 2005 in Renda Civil Parish (*pagasts*) of Kuldīga District (here and below, the name of the parish corresponds to the name of the respective forest district), Engure Civil Parish of Tukums District, and in 2006 in Saka Civil Parish of Liepāja District, Jaunsvirlauka Civil Parish of Jelgava District and Zaņa Civil Parish of Saldus District. Ring-width data obtained slightly earlier from six sample areas in Kolka Civil Parish of Talsi District were also used (Fig. 1).

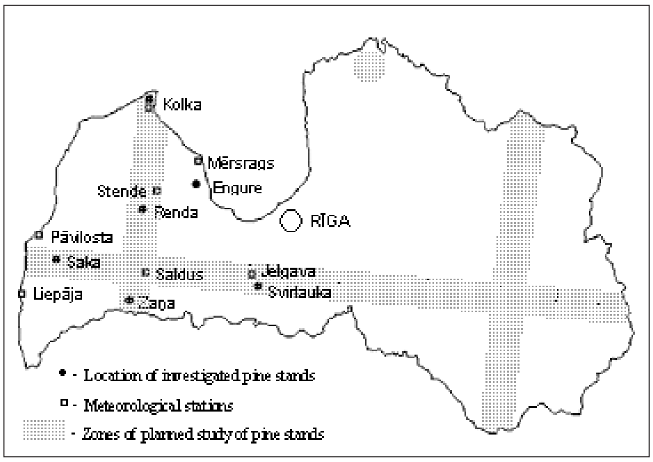

Fig. 1. Map showing the wood sampling locations and the closest meteorological stations.

Sampled stands were on dry mineral soils: *Vacciniosa* (*mētrājs*), *Myrtillosa* (*lāns*) or *Hylocomiosa* (*damaksnis*). In Kolka Civil Parish a *Cladinoso-callunosa* (*sils*) site type was also included.

To assess and characterise the influence of climatic factors on tree growth over a long period as objectively and precisely as possible, the wood samples were collected in preselected pine stands that had reached felling age. In practical terms, the samples were collected in the form of discs, sawn from old pine stumps remaining after recent clearfelling. Between 14 and 19 disc samples of wood were sawn from these stumps in a single clearing or in two or three nearby clearings in each forest district. This number of samples was deliberately chosen, since previous dendrochronological research had indicated that mean values of tree-ring width obtained from such a number of wood samples provided a sufficiently precise and objective reflection of the mean pattern of year-by-year radial tree growth for the whole stand. In the Kolka area a larger number of trees was sampled (62). Here, in contrast to the other sites, one core was obtained from each selected pine using a Pressler borer (Table 1).

Ring-width measurement and statistical processing of the data. Tree-ring width was measured using a *Lintab* table (*Rinntech* company, Germany), with a precision of 1/100 mm. The ring widths were measured in three radial directions on each disc sample, calculating the mean width of each ring. Recording, checking and standardisation of tree rings, and cross-dating of the resulting ring-width indices, was undertaken using the Sakore V.3, Cofecha and TSAP software[1] (Grissino-Mayer *et al.*, 1996; Rinn, 1996; Grissino-Mayer, 2001). The tree-ring chronologies were produced using the Arstan programme (Grissino-Mayer *et al.*, 1996). Standard chronologies were calculated to estimate the dendrochronological signal, and multivariate regression operated on the "residual" chronology, obtained af-

[1] Zunde, M. Kultūrvēsturisko un dabas objektu dendrohronoloģiskā datēšana un tās perspektīvas Latvijā [Dendrochronological dating of historical and natural sites and its future prospects in Latvia]. Doctoral thesis, University of Latvia, Rīga, 2003, pp. 42–47 (in Latvian).

ter double detrending and subsequent modelling of autoregression (Grissino-Mayer *et al.*, 1996).

The similarity of tree-ring chronologies was estimated by time series procedure: the percentage of parallel variation (Gleichläufigkeit), the correlation coefficient for paired samples and its significance test, the t-value.

Signature or marker years were identified for the period covered by the chronologies for all six forest districts. Signature years are years in which the ring-width shows a synchronous reduction or increase in more than 90% of 10 or more trees (Schweingruber, 1983). In our case, the number of time series for comparison was less than 10, but we considered tree stands and not individual trees. The signature years were also determined by comparing the chronologies obtained with absolute chronologies for pine in Estonia and Lithuania, produced by A. Läänelaid and A. Vitas (Läänelaid and Eckstein, 2003; Vitas, 2008).

Data on climatic factors. The climatic factors considered in the study include mean air temperature and total precipitation by calendar month, and for the four seasons of the pine vegetation year: 1) September – November (autumn), 2) December – February (winter), 3) March – May (spring) and 4) June – August (summer). The meteorological data required was obtained from the Faculty of Geography and Earth Sciences of the University of Latvia, and from the Latvian Environment, Geology, and Meteorology Agency, for the meteorological and hydrometeorological stations closest to the study areas: Jelgava, Kolka, Liepāja, Mērsrags, Pāvilosta, Saldus, and Stende (Fig. 1).

Analysis of changes in tree-ring width indices and meteorological data. A relationship between tree-ring width and climatic factors was shown by statistically significant correlation (at $\alpha = 0.05$). In order to determine the periods when particular meteorological factors most significantly influenced radial tree growth in each forest district, multivariate regression was performed. Both correlation and multivariate regression were carried out using the SPSS package (Morgan *et al.*, 2004). Particular calendar months in which the influence of meteorological factors on the annual radial growth of the pines under study was statistically significant were additionally determined using DendroClim 2000 (Biondi and Waikul, 2004) and MS Excel, comparing year by year the direction of change in climatic factors for various periods with the direction of change of radial tree growth.

RESULTS

Correlation coefficients r for the mean radial growth of pine were calculated between stems within one stand or several nearby stands (Kolka area) (Table 1).

The coefficients of determination ($D = r^2$) given in Table 1 indicate that in the forest stands of the all five forest districts, except Kolka, 3–5% up to 35–45% (in one case even 58%), or a mean 13–16%, of the fluctuation in ring width of

Table 1

CORRELATION COEFFICIENTS (r) AND COEFFICIENTS OF DETERMINATION (D) BETWEEN FOREST STANDS IN RADIAL GROWTH OF PINES

Forest district	r_{mean}	r_{min}	r_{max}	D_{mean}	D_{min}	D_{max}
Engure	0.36	0.19	0.58	0.13	0.04	0.34
Renda	0.36	0.18	0.59 (0.76)	0.13	0.03	0.35 (0.58)
Saka	0.40	0.19	0.67	0.16	0.04	0.45
Svirlauka	0.37	< 0.19	0.58	0.14	0.04	0.34
Zaņa	0.37	0.23	0.59	0.14	0.05	0.35
Kolka*						
a)	0.40	0.23	0.59	0.16	0.05	0.35
c)	0.49	0.33	0.69	0.24	0.11	0.48
d)	0.43	0.31	0.55	0.18	0.10	0.30
e)	0.39	0.17	0.68	0.15	0.03	0.46
f)	0.41	0.18	0.59	0.17	0.03	0.35
g)	0.41	0.21	0.62	0.17	0.04	0.38

* a)–g) – six sample areas in Kolka Civil Parish

the pine trunks is explained by the influence of general ecological factors, i.e. mainly climatic factors. The minimum values of the correlation coefficient r, and thus also the mean values, given in the table for the pines studied in the Kolka area, may be slightly larger than the true values, since the study did not make use of the time series of tree ring widths for some of the trees studied in this area, which differed too much from the other, either because of the poor quality of the wood sample, or for other reasons.

The significance of the correlation coefficient is measured by the t-value, the statistic most commonly used in dendrochronology. Judging from the high t-values, the pines in the Kolka area, where only single cores were taken, more commonly showed a markedly similar annual radial increment, possible due to older age of trees (Table 2). This may ex-

Table 2

MEAN t-VALUES AND CONFIDENCE LEVEL FOR TREE RING SERIES FOR PINES FROM SIX DISTRICTS OF LATVIA

Forest district	No. of samples	No. of annual rings in samples		Mean t-value	Confidence level
		Range	Mean		
Engure	14	113–140	127	3.9	0.999
Renda	17	86–172	137	4.2	0.9999
Saka	18	107–172	117	4.8	0.9999
Svirlauka	19	100–128	115	4.2	0.9999
Zaņa	15	79–133	117	4.3	0.9999
Kolka*					
a)	11	157–184	172	5.6	> 0.9999
c)	12	96–126	108	5.8	> 0.9999
d)	6	104–166	143	5.4	> 0.9999
e)	13	52–177	72	3.2	0.995
f)	12	61– 87	75	3.7	0.999
g)	8	52– 62	75	3.7	0.999
Total:	62				
Overall total:	145				

* a)–g) – six sample areas in Kolka Civil Parish

plain why in some of the studies previously undertaken in Latvia, a correlation between the annual increment in wood and climatic factors was most commonly found to be low: when core samples are collected from growing trees, the influence of climatic factors on tree development is often assessed over a relatively short period. It is generally not possible to characterise a tree's reaction to the influence of climatic factors adequately from a time series consisting of only about 50 ring-width indices.

The influence of climatic factors on the annual radial growth of trees is clearer in ring-width chronologies where the variation in annual ring-width index values connected with local factors is minimal. However, climatic factors are influenced also by the growing conditions in the study area, and thus also by the distance between the sampling sites of the trees. In the chronologies for smaller areas, the variation in annual ring width caused directly by global, i.e. mainly climatic factors, which have fluctuated at a larger scale, is reflected relatively more weakly. In assessing the t-values, characterising the significance of the correlation between chronologies, the influence of the size of the area in which the sampled trees have been growing should also be taken into account.

The t-values given in Table 3 show that the correlation between any two chronologies compiled is significant (t-value 3.5, P 0.0001, and a t-value of 6.0 is regarded as a secure indication that two time series are synchronous (Krąpiec, 1998). In the present case, the t-values obtained (ranging from 4.2 to 9.1) show that in the western part of Latvia, over distances of at least 155 km, the discrimination of the common dendrochronological signal in the local tree-ring chronologies can be viewed as very good, and thus, climatic factors have a significant influence on the radial increment of the trunks of pines growing in the environmental conditions of Latvia.

Table 3

T-VALUES FOR COMPARISON ON RING-WIDTH CHRONOLOGIES FOR THE STUDY STANDS

Forest district	Engure	Renda	Saka	Svirlauka	Zaņa	Kolka
Engure	0	5.4	5.4	5.0	9.1	7.2
Renda	5.4	0	8.9	6.6	7.4	5.6
Saka	5.4	8.9	0	7.5	7.5	4.4
Svirlauka	5.0	6.6	7.5	0	6.4	4.2
Zaņa	9.1	7.4	7.5	6.4	0	6.9
Kolka	7.2	5.6	4.4	4.2	6.9	0
Mean	**6.4**	**6.8**	**6.7**	**5.9**	**7.5**	**5.7**

In the phase of research undertaken so far, when we compare any two ring-width chronologies for stands separated by a distance of approximately 55 to 155 km, no direct relationship is found between the distance separating them and the t-value characterising the similarity between the two time series, possibly due to other factors.

Table 4

CORRESPONDENCE (%) BETWEEN THE DIRECTION OF CHANGE OF THE ANNUAL VARIATION IN PRECIPITATION DETERMINED FOR THE FOUR SEASONS OF THE VEGETATION YEAR AND THE MEAN VALUE OF THE TREE-RING WIDTH INDICES

Forest district	XII – II	III – V	VI – VIII	IX – XI
Svirlauka	50.1	45.3	52.8	49.1
Saka	56.1	49.5	57.0	57.0
Engure	48.6	57.0	53.3	46.7
Renda	57.5	47.5	52.5	42.5
Kolka	48.1	50.0	55.6	48.1
Zaņa	49.3	47.8	56.5	52.2
Mean:	**51.62**	**49.52**	**54.62**	**49.27**

In western Latvia, no clear relationship was observed between the precipitation in any particular season or month of the pine vegetation year (from September of the previous year up to August of the current year) and the mean annual radial increment of pine in that year. However, there is a weak tendency of increased radial growth compared to the previous years in years with increased precipitation during summer (July–August). The effect of precipitation in mineral soils with normal moisture conditions was evidently weak compared to strong dependence on many other factors that influencing the growth of pine.

The annual radial growth of pine in the western part of Latvia was most significantly influenced directly by the mean air temperature in the months of the second half of winter and especially the first half of spring.

Table 5

CORRESPONDENCE (%) BETWEEN THE DIRECTION OF ANNUAL CHANGE IN MEAN AIR TEMPERATURE FOR THE FOUR SEASONS OF THE VEGETATION YEAR AND THE MEAN VALUES OF RING-WIDTH INDICES

Forest district	XII – II	III – V	VI – VIII	IX – XI	II – IV
Svirlauka	59.1	70.1	49.6	50.4	67.0
Saka	64.5	69.2	62.6	49.5	68.4
Engure	50.9	63.9	60.2	50.9	65.7
Renda	62.5	66.3	57.5	45.0	71.3
Kolka	63.2	59.2	55.3	52.6	64.5
Zaņa	56.4	60.0	40.0	50.9	62.5
Mean:	**59.43**	**64.78**	**54.20**	**49.88**	**66.57**

This trend is most evident by examination of the direction of change in the mean ring-width in relation to the direction of change of the mean temperature in the particular season of the vegetation year for the signature years, which can be expected as the growth of trees was particularly influenced by large-scale climatic factors. In 74–82% of the total number of signature years, the ring-width of the studied pines and the mean air temperature during the spring season changed in the same direction, compared with the preceding year.

Similar results were obtained using other methods. All the ring-width chronologies, apart from the chronology for Kolka, which was not used in this phase of the study, show a significant correlation (at $\alpha = 0.05$) with mean air temperature for February, March and partly also April (Table 6). In the majority of cases, increased precipitation in June of the vegetation year also had a positive influence on the radial growth of pine.

Table 6

SIGNIFICANT CORRELATION COEFFICIENTS (AT $\alpha = 0.05$) FOUND BETWEEN THE RING-WIDTH CHRONOLOGIES AND THE TIME SERIES OF MEAN MONTHLY AIR TEMPERATURE *

	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
Svirlauka					0.22	0.41	0.47	0.28				0.21
Saka						0.30	0.33	0.24				
Engure					0.23	0.39	0.34	0.19				
Renda						0.48	0.51	0.25				0.36
Zaņa						0.33	0.30					

* Non-significant values are omitted

The effect of mean air temperature in February, March, and partly also April on radial growth was confirmed by multivariate regression. Climatic factors explained 16.2% of the ring-width chronology variation for Engure, 35.3% for Renda, 15.5% for Saka, 25.1% for Svirlauka, and 20.9% for Zaņa. Differences between these values can partly be explained by local factors. In the absence of comparative data from other regions of Latvia, it is at present difficult to explain the importance of mean air temperature in March–April on the radial growth of pine (Table 1).

It is important to assess the differences in the explained variation for the chronologies in relation to climatic factors in various parts of Latvia.

Air temperature and precipitation in the study region are determined by their location by the Baltic Sea and Gulf of Rīga, and by relief features. One of the most important factors determining air temperature and precipitation amount are the prevailing air masses. Maritime air masses (37–40% of cases) and modified maritime air masses (45–49% of cases) dominate, while continental air masses are less commonly (13–15% of cases) (Draveniece, 2007). When continental air masses prevail, the range of variation in air temperature and regional differences are greater than in the case of moist maritime air masses. The mean annual differences in air temperature within the region are up to 1 ^{o}C. The highest mean annual air temperature is observed in the Liepāja area (+6.7 ^{o}C), and the lowest in the upland parts of Kurzeme - around Stende and Saldus (+5.7 ^{o}C). At the Baltic Sea coast (for example, in the Liepāja and Pāvilosta areas), winters and autumns are warmer, while springs are cooler. The warmest air temperature in spring and summer is in the continental area (around Jelgava). Overall, the positive and negative deviation in mean air temperature during the summer season is ±2 ^{o}C to ±3 ^{o}C, and even greater in the winter and spring seasons. The mean range of variation in seasonal air temperature within the region is 1.9 ^{o}C for the winter and spring seasons, 1.8 ^{o}C in the autumn, and lower in the summer: 0.9 ^{o}C.

The relatively greater range of variation in mean air temperature in both winter and spring evidently results in a greater impact on the physiological processes of woody plants. Currently, we can only hypothesise that the variation in chronologies explained by climatic factors is lower for the pine chronologies for Engure and Saka than for the other chronologies, due to the influence of cooler springs, characteristic of these coastal areas, and the more significant influence of a relatively shallower groundwater level. In the study region, precipitation, in contrast to air temperature, varies less in winter and spring than in the summer and autumn seasons: in winter and spring, mean precipitation between meteorological stations in the study area differs by 20 mm, in summer by 44 mm, and in autumn by 33 mm. This may explain why increased precipitation amount in early summer was correlated with radial growth of the studied pines in this period. The distribution of precipitation across the region is not uniform, mainly due to relief. In the upland areas of Kurzeme and especially on their windward side, annual precipitation is generally more than 700 mm, while along the coast of the Gulf of Rīga it is only 570–580 mm, a difference of about 150 mm. Also the annual pattern of distribution of precipitation also differs: in the continental part (Jelgava, Saldus and Stende), maximum precipitation occurs in the middle of summer (July), while in coastal areas the highest precipitation is usually observed in the second half of summer and autumn.

While radial growth of pine in the Kurzeme area is most significantly affected by mean air temperature from the second half of January to the first half of April, this relationship is not always well seen. Table 7 shows the 64 signature years recorded during a 101-year period. In some cases changes of a similar character in radial growth can, and usually do, occur due to the influence of various local factors. However, in the majority of cases the changes in ring-widths observed across a large area, can be explained by the changing influence of global factors, mainly climatic. In 37 years of the 64 signature years (57.8%), the direction of change in mean radial increment corresponded to the direction of change in the mean air temperature for the months of December–February, and for March–May of that vegetation year (compared with the preceding year). In a total of eight years (12.5%), the direction of change in the mean radial increment of pine corresponded to the direction of change of mean air temperature in the first period—December–February, and in 11 years (17.2%) it corresponded to the direction of change of mean air temperature in the second period—March–May. However, in eight years (12.5%), the mean radial increment of pine changed in the opposite direction to the changes in mean air temperature in both the winter and spring periods (after a relatively warmer winter and spring, the radial increment of the majority of studied trees fell in 1932, 1981, 1992 and 1998, while in years with a relatively

Table 7

SIGNATURE YEARS IN THE PERIOD 1900 TO 2000

W	S	PY–	Year	Year	PY+	W	S
				1903	++	(+)	+
(–)	–		1904				
				1906	+	+	+
–	–	-	1907				
				1910	+	+	+
(+)	(–)	--	1914				
				1916	++	–	+
–	–	--	1917				
				1919		(+)	–
				1922		–	–
+	–		1923				
–	–	-	1924				
				1925	++	+	+
–	–	--	1926				
=	–	--	1928				
–	–		1929				
				1930		+	+
–	–		1931				
+	(+)	-	1932				
				1934		+	+
–	–		1935				
				1936		+	+
				1938		+	(–)
–	–	--	1940				
				1941		+	(–)
				1943	++	+	+
				1945	++	–	+
–	–	--	1947				
				1948	++	+	+
+	(–)		1949				
(–)	–	-	1951				
+	–	--	1952				
				1953	+	–	+
–	–	-	1954				
				1955	+	+	–
–	+		1956				
				1957	++	+	+
–	–	--	1958				
				1959		+	+
–	–	--	1962				
–	+		1966				
				1967	++	+	+
(–)	–	--	1969				
				1970	++	–	+
				1972	++	–	(+)
				1974		–	–
–	–	--	1976				
–	+		1977				
				1978		=	(+)
+	–		1980				
+	+	-	1981				
–	–	-	1985				
				1986		+	+
				1987		–	–
				1988		+	+
				1989	+	+	+
–	–		1991				
+	+		1992				
–	–		1994				
				1995	++	+	+
				1996		–	–
+	+	--	1998				
				1999		–	(+)

Symbols used in columns PY– and PY+ :

– – , ++ – signature years, when the tree-ring index values fell or increased in all the chronologies compiled, as well as in the chronologies for Lithuania and Estonia;

–, + – signature years, when tree-ring index values in the opposite direction are observed only in the chronology for Lithuania and/or Estonia;

[empty cells next to year numbers] – signature years, when tree-ring index values changed in the same direction in five out of six of the chronologies (regardless of the direction of change in the chronologies for Lithuania and Estonia);

Symbols used in columns W and S:

W – the direction of change of mean air temperature, compared with the preceding year, in the period XII–II;

S – the direction of change in mean air temperature, compared with the preceding year, in the period III–V

[empty box] – mean air temperature changes in the same direction as tree-ring index value (correspondence);

[hatched box] – mean air temperature changes in opposite direction to tree-ring index value (non-correspondence)

lower mean air temperature in both winter and spring, the radial growth of trees nevertheless increased in 1922, 1974, 1987 and 1996). The year 1942 also differs, for example: in the winter and spring periods of this year, the mean air temperature was even lower overall than in 1940—a pronounced signature year in which the majority of pines in Latvia showed the most dramatic reduction in radial growth during the whole of the 20th century.

Deviation from a direct relationship between mean air temperature for the winter and spring months and ring-width of pine for that year can result from the non-climatic factors, the significance, character and degree of which need to be focussed in future dendroclimatological and dendroecological studies.

DISCUSSION

The results of the study correspond well with the results of dendroclimatological studies undertaken in countries near to Latvia. In northern Norway, Finland and Sweden, where the vegetation season is shorter and where Scots pine reaches the northern limit of its range, the growth of pine is influenced mainly by mean air temperature in the summer months, particularly in July (Eggertsson, 2000; Kirchhefer, 2001; Helama *et al.*, 2003; Linderson, 2003). Some researchers consider that older pines in northern Finland have been more affected by mean air temperature in July of the preceding year (Salminen and Jalkanen, 2004; Pensa *et al.*, 2005). Further to the south, in south-eastern Finland, mean summer temperatures have little effect on the annual growth of pine, and it is impossible to isolate a single factor determining tree growth: sometimes the mean air temperature in the months of April to September has a greater influence, but at other times precipitation has a greater impact (Lindholm and Meriläinen, 1998; Lindholm *et al.*, 1998–1999). In south-eastern Sweden, the radial growth of pine is more affected by mean air temperature in November, and sometimes also October and December, of the preceding year, but also, as in the northern regions, mean air temperature in July is a contributing factor (Linderson, 2000). In the southern Fennoscandia the development of pine is most influenced by mean air temperature in late winter and early spring, i.e. from January to April/May (Linderson, 1992; 2003), which is also true for Latvia and the other two Baltic States, as well as for the northern parts of Poland and Germany (Krause, 1992; Juknys and Vencloviene, 1998; Cedro, 2001; Läänelaid and Eckstein, 2003; Pärn, 2003; Krąpiec and Szychowska-Krąpiec, 2005; Vitas, 2006). Further to the north, the radial growth of pine is most significantly determined by summer air temperature (particularly in July).

In the USA the radial growth of conifers in low-lying areas depends mainly on climatic conditions in the winter period (Fritts, 1996), which partly confirms the conclusion drawn by E. Špalte that in Latvia the radial growth of pine is most dependent on mean air temperature in March (Špalte, 1975a). It is possible that in eastern Latvia, which has a more continental climate and higher relief than the western part of the country, radial growth of pine depends more on other climatic factors. It would also be useful to consider in future dendroclimatological research how climatic factors during the preceding vegetation season affect the radial growth of trees. As the latewood of pines in this region begins to form approximately in early July, and knowing that cool and wet summers result in the formation of a narrower latewood ring, the width of the earlywood and latewood of the annual ring should be separately analysed in dendroclimatological studies. The results of the research undertaken so far show that it is more difficult to objectively assess the influence of climatic factors in summer from tree-ring width in cases where the latewood formed in summer often constitutes only a small part of the annual ring.

The results of the study confirm that the influence of the dendrochronological signal is sometimes weakly reflected in the time series of ring widths of individual pines growing in the environmental conditions of Latvia, but in time series of mean values of ring-width indices compiled from ring-width data on more than 10 trees this influence is generally found to be significant. The assessment of the influence of the dendrochronological signal and its reflection is usually also less objective if the ring-width for a tree is measured only in one radial direction and if the time series of ring widths cover a period of less than 70–80 years, or sometimes even 100 years.

The results obtained do not yet fully and precisely characterise the influence of climatic factors on the radial growth of Scots pine throughout the territory of Latvia. In order to obtain more comprehensive and objective information, it is necessary to continue the research, both in similar growing conditions in the eastern part of Latvia, and in different growing conditions throughout the territory of Latvia, to successfully reconstruct the changing influence of environmental factors in the territory of Latvia in the past and to forecast the future influence

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REFERENCES

Biondi, F., Waikul, K. (2004). Dendroclim 2002: A C++ program for statistical calibration of climate signals in tree ring chronology. *Comput. Geosci.*, **30**, 303–311.

Cedro, A. (2001). Dependence of radial growth of *Pinus sylvestris* L. from western Pomerania on the rainfall and temperature conditions. *Geochronometria*, **20**, 69–74.

Draveniece, A. (2007). Okeāniskās un kontinentālās gaisa masas Latvijā [Maritime and continental air masses in Latvia]. *Latvijas Veģetācija*, **14**, 135 lpp.

Eggertsson, Ó. (2000). Annual growth studies of pines (*Pinus sylvestris* L.) from the boreal forest of Northern Europe, a preliminary report. In Kolström, T., Lindholm, M., Viinanen, R. (eds.). Conifer growth variability during the Holocene in Northern Europe. Proceedings of the Meeting, 16–19 March 2000 (pp. 15–23). Lund, Sweden: Tiedonantoja/Research Notes 108. University of Joensuu, Faculty of Forestry.

Fritts, H.C. (1996). Growth-rings of trees: Their correlation with climate. *Science*, **154**(3752), 937–979.

Grissino-Mayer, H.D. (2001). Evaluating crossdating accuracy: A manual and tutorial for the computer program COFECHA. *Tree-Ring Research*, **57**(2), 205–221.

Grissino-Mayer, H.D., Holmes, R.L., Fritts, H.C. (1996). *User's Manual for the International Tree-Ring Data Bank Program Library Version 2.0.* Tucson, Arizona: Laboratory of Tree-Ring Research, University of Arizona. 110 pp.

Helama, S., Holopainen, J., Lindholm, M., Ogurtsov, M.G., Timonen, M., Eronen, M. (2003). Using early meteorological observations from 18th and 19th centuries to test relationship between summer temperature and growth in Northern Finland. In *EuroDendro 2003.* Conference of the European Working Group for Dendrochronology, 10–14 September 2003 (p. 37). Obergurgl Tyrol, Austria: The Institute of High Mountain Research, Innsbruck.

Jātnieks, J. (1991). Fona monitorings Krustkalnu rezervātā [Background monitoring in the Krustkalns Reserve]. In *Teiču rezervāts* (2.–29. lpp.). Rīga: Latvijas informācijas centrs (in Latvian).

Juknys, R., Vencloviene, J. (1998). Quantitative analysis of tree ring series. In Stravinskiene, V., Jyknus, R. (eds.), *Dendrochronology and Environmental Trends.* Proceedings of the International Conference, 17–21 June 1998, Kaunas, Lithuania. (pp. 237–249). Kaunas: Vytautas Magnus University.

Kirchhefer, A.J. (2001) Reconstruction of summer temperatures from tree-rings of Scot pine (*Pinus sylvestris* L.) in coastal northern Norway. *The Holocene*, **11**(1), 41–52.

Krąpiec, M. (1998). Oak Dendrochronology of the Neoholocene in Poland. In Krąpiec, M. (ed.), *Folia Quaternaria 69: Progress in Dendrochronology of the Last Millenia in Poland* (p. 9). Kraków, Polska Akademia Umiejętności.

Krąpiec, M., Szychowska-Krąpiec, E. (2005). Paleoclimatological interpretation of Scots Pine chronology from NE Poland. In Sarlatto, M., Di Filippo, A., Piovesan, G. & Romagnoli, M. (eds.), *EuroDendro 2005*. Abstract Book of International Conference of Dendrochronology, 28 September – 2 October, Viterbo, Italy (pp. 55–56). Viterbo: Sette Cittą.

Krause, C. (1992). Climate-growth relationships from continuous tree-ring series versus pointer years. In Bartholin, T.S., Berglund, B.E., Eckstein, D., Schweingruber, F.H. (eds.), Eggertsson, Ó. (man. ed.). *Tree Rings and Environment*. Proceedings of the International Dendrochronological Symposium, 3–9 September 1990 in Ystad, South Sweden. LUNDQUA Report, 34 (pp. 164–167). Lund: Lund University, Department of Quaternary Geology.

Läänelaid, A., Eckstein, D. (2003). Development of a tree-ring chronology of Scots Pine (*Pinus sylvestris* L.) for Estonia as a dating tool and climatic proxy. *Baltic Forestry,* **9** (2), 76–82.

Liepa, I. (1972). Vides faktoru ietekmes īpatsvara noteikšana ar multiplās regresijas metodi [The determination of the relative influence of environmental factors by multivariate regression]. *Jaunākais Mežsaimniecībā*, **14**, 47.–50. lpp. (in Latvian).

Linderson, H. (1992). Dendroclimatological investigation in Southern Sweden. In Bartholin, T.S., Berglund, B.E., Eckstein, D., Schweingruber, F.H. (eds.), Eggertsson, Ó. (man. ed.), *Tree Rings and Environment.* Proceedings of the International Dendrochronological Symposium, 3–9 September 1990 in Ystad, South Sweden. LUNDQUA Report, 34 (pp. 198–201). Lund: Lund University, Department of Quaternary Geology.

Linderson, H. (2000). Conifer growth in boreal forests of northern Sweden related to meteorological data. In Kolström, T., Lindholm, M., Viinanen, R. (eds.) *Conifer growth variability during the holocene in Northern Europe.* Proceedings of the Meeting 16–19 March, 2000 in Lund, Sweden. Tiedonantoja/Research Notes 108 (pp. 25–35). Joensuu: University of Joensuu.

Linderson, H. (2003). A comparison between tree-ring widths of recent Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) stands and meteorological data from two areas in Sweden—inferences for the use of tree-ring width as climate indicator. In: *LUNDQUA Report 38* (pp. 8, 14). Lund: Department of Geology, Quaternary Geology, Lund University.

Lindholm, M., Meriläinen, J., Eronen, M. (1998–1999). A 1,250-year ring-width chronology of Scots pine for south-eastern Finland, in the southern part of the boreal forest belt. *Dendrochronologia*, 16–17, 183–190.

Lindholm, M., Meriläinen, J. (1998). An over 1000-year ring-width chronology of Scots pine for south-eastern Finland. In Stravinskiene, V., Jyknus, R. (eds.), *Dendrochronology and Environmental Trends.* Proceedings of the International Conference, 17–21 June, 1998, Kaunas, Lithuania. (pp. 271–276). Kaunas: Vytautas Magnus University.

Morgan, G.A., Leech, N.L., Gloeckner, G.W., Barrett, K.C. (2004). *SPSS for introductory statistics—use and interpretation.* New Jersey: Lawrence Erlbaum Associates. 211 pp.

Pärn, H. (2003). Radial growth response of Scots pine to climate under dust pollution in Northeast Estonia. *Water, Air and Soil Pollution*, **144**, 343–361.

Pensa, M., Salminen, H., Jalkanen, R. (2005). A 250-year-long height-increment chronology for *Pinus sylvestris* at the northern coniferous timberline: A novel tool for reconstructing past summer temperatures? *Dendrochronologia*, **22**(2), 75–81.

Received 6 May 2008

Rinn, F. (1996). *TSAP Reference Manual (version 3.0)*. Heidelberg: Frank Rinn. 263 pp.

Salminen, H., Jalkanen, R. (2004). Does current summer temperature contribute to the final shoot length on *Pinus sylvestris*? A case study at the northern conifer timberline. *Dendrochronologia*, **21**(2), 79–83.

Schweingruber, F.H. (1983). *Der Jahrring. Standort, Methodik, Zeit und Klima in der Dendrochronologie*. Bern; Stuttgart: Paul Haupt Verlag. S. 93.

Špalte, E. (1975a). Meteoroloģisko faktoru ietekme uz parastās priedes radiālo pieaugumu [The influence of meteorological factors on the radial increment of Scots pine]. *Jaunākais Mežsaimniecībā*, **18**, 46–53 (in Latvian).

Špalte, E. (1975b). Meteoroloģisko faktoru ietekme uz parastās priedes gadskārtu platumu [The influence of meteorological factors on the width of tree-rings in Scots pine]. *Mežsaimniecība un Mežrūpniecība*, **1**, 32–35 (in Latvian).

Vitas, A. (2006). Sensitivity of Scots pine trees to winter colds and summer drougthts: Dendroclimatological investigation. *Baltic Forestry*, **12**(2), 220–226.

Vitas, A. (2008). Litpinus-1: Tree-Ring Chronology of Scots Pine (*Pinus sylvestris* L.) for Lithuania. *Baltic Forestry*, **15**(2), in press.

Zālītis, P., Šitca (1986). Kokaudžu ražība ekstrēmi sausās vasarās [The productivity of tree stands in extremely dry summers]. *Jaunākais Mežsaimniecībā*, **28**, 24–29 (in Latvian).

Zviedris, A. (1950). Piezīmes par klimatisko faktoru ietekmi uz egļu stumbru caurmēra pieaugumu [Notes on the influence of climatic factors on the diameter increment of spruce trunks]. *Latvijas PSR Zinātņu Akadēmijas Vēstis*, **9**(38), 105–108 (in Latvian).

Zviedris, A., Sacenieks, R. (1958). Klimatisko faktoru ietekme uz priežu stumbru caurmēra pieaugumu [Influence of climatic factors on the diameter increment of pine trunks]. *Latvijas PSR Zinātņu Akadēmijas Vēstis*, **5**(130), 37–44 (in Latvian).

Залитис, П.П. (1967). *Динамика сезонного прироста деревьев в осушенных сосняках и ельниках осоково-тростниковых* [Dynamics of seasonal increment in drained forest site type Caricosphragmitosum]. Елгава: ЛСХА. 25 с. (in Russian).

Звиедрис, А.И., Сацениекс, Р.Я. (1960). О влиянии климатических факторов на ширину годичных слоев ели [Influence of climatic factors on the width of annual rings in spruce]. *Известия АН Латв. ССР*, **3**(152), 177–184 (in Russian).

Лиепа, И.Я. (1980). *Динамика древесных запасов: прогнозирование и экология* [Dynamics of Wood Stocks: Forecasting and Ecology]. Рига: Зинатне, 171 pp. (in Russian).

Скудра, П.Я. (1988) Влияние климатических факторов на формирование прироста по запасу хвойных древостоев [Influence of climatic factors on the formation of increment in coniferous forest stands]. В кн. *Труды ЛСХА*, Вып. 194, Елгава, с. 58–65.

Шпалте, Э.П. (1978). Влияние метеорологических факторов на радиальный прирост сосны в Латвийской ССР [Influence of meteorological factors on radial increment of *Pinus Sylvestris* L. in the Latvian SSR]. *Лесоведение*, **3**, 11–18 (in Russian).

KLIMATISKO FAKTORU IETEKME UZ PARASTO PRIEŽU (*Pinus sylvestris* L.) GADA RADIĀLO PIEAUGUMU LATVIJAS RIETUMDAĻĀ

Dendroklimatoloģiskie pētījumi Latvijā atsākti pēc aptuveni 25 gadu ilga pārtraukuma. Pētījumā analizēta Latvijas rietumdaļas sešos rajonos augušu parasto priežu (*Pinus sylvestris* L.) augšanas gaita atkarībā no klimatiskajiem faktoriem (gaisa vidējās temperatūras un nokrišņu daudzuma) gada atsevišķās sezonās un mēnešos. Lietojot vairākas datu statistiskās apstrādes metodes, apstiprināts, ka minētajā teritorijā priežu augšanu normāla mitruma minerālaugsnēs visbūtiskāk ietekmējusi gaisa vidējā temperatūra laikposmā no attiecīgā gada janvāra otrās puses līdz aprīļa pirmajai pusei. Tādējādi šis gaisa vidējās temperatūras būtiskākās ietekmes laiks ir līdzīgs teritorijas posmā vismaz no Lietuvas (ieskaitot) līdz Skandināvijas valstu dienvidu daļai, bet tālāk uz ziemeļiem par priežu radiālā pieauguma noteicošo faktoru pakāpeniski kļūst gaisa vidējā temperatūra vasarā. Izpētes gaitā noteikta un vērtēta arī dendrohronoloģiskā signāla ietekmes atspoguļojuma kvalitāte Latvijas vides apstākļos augušo priežu gadskārtu hronoloģijās, kā arī noskaidroti t.s. signatūras gadi 20. gadsimtā, kuros konstatēta līdzīga rakstura ikgadējā radiālā pieauguma izmaiņas vairākumam priežu visā Baltijas valstu teritorijā.