A Dendroclimatological Analysis of European Larch (*Larix decidua* Mill.) from Lithuania

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Vitas, A. 2015. A Dendroclimatological Analysis of European Larch (*Larix decidua* Mill.) from Lithuania. *Baltic Forestry* 20(2): 65–72.

Abstract

This study presents results of a dendroclimatological study on the radial growth of European larch (*Larix decidua* Mill.) in Lithuania. Analysis of response function has shown that tree-ring widths of larch are inversely correlated with air temperature in the previous summer, and directly related to temperature in April–May and precipitation in June of the current growth season. The sharp decreases in radial growth were mainly provoked by droughts in summer; positive pointer years were triggered by warmer conditions and abundant precipitation in summer. The light rings in larch coincide with negative pointer years and perhaps contain a non-climatic signal.

Key words: European larch, radial growth, climatic factors, climatic extremes, light rings, Lithuania

Introduction

Although larch trees were planted in Lithuania as early as at the beginning of the 19th century (Januškevičius 2004), little information is available on the influence of climatic factors on tree-ring formation. European larch is one of the most beautiful planted trees in parks and forests. Tree rings of larch are valuable for dendrochronological investigations because the trees are fairly old and tree-ring boundaries are clearly visible (Büntgen et al. 2008, Serre 1978). Earlier studies usually were based on one or few research plots and controversial results were obtained because of different methods.

According to earlier results, the radial growth of larch is less sensitive to winter colds than Scots pine (Kaselytė 2003, Pukienė and Bitvinskas 2000). The positive influence of precipitation in summer was observed by Pukienė and Bitvinskas (2000) and later confirmed by Kaminskaitė (2002). The positive influence of cool weather in previous summer was also noticed by Pukienė and Bitvinskas (2000). The aforementioned results were confirmed by Vitas and Žeimavičius (2011), who found an inverse link with air temperature in previous July, which is significant in many research plots.

Pointer years were detected from a regional chronology of larch in Lithuania (Vitas and Žeimavičius 2011). They have proven that hot and dry summers were responsible for sharp decreases in the radial growth. However, the spatial distribution of pointer years was not performed.

Many studies on tree rings of larch have been accomplished in the Alpine region (Büntgen et al. 2008, Huesken, 1993, Kress et al. 2009, Serre 1978). It was found that the main factor determining narrow tree rings is low temperature in summer (Büntgen et al. 2008, Serre (1978). In addition, Serre (1978) observed the negative influence of cold winter and abundant precipitation in summer on larch radial growth. Polster (1967) defined a higher water demand of larch than of Scots pine. In Poland, an inverse effect of previous summer temperature and positive influence of precipitation in summer were found (Oleksyn and Fritts 1991, Koprowski 2012). In addition, Oleksyn and Fritts (1991) have observed high mean sensitivity of larch tree-ring widths in Poland.

According to Filion et al. (1986), light ring refers to a latewood zone with thin-walled low lignification cells. Light rings were observed in the growth of larch in Estonia (Läänelaid 2007) and Lithuania (Vitas and Žeimavičius 2010). At present, it is still not clear do they contain any climatic signal.

The aims of this study were to (1) assess the tree-ring growth / climate relationships using response function and pointer year analysis in a network of research plots of larch in Lithuania and (2) to perform a spatio-temporal analysis of the response function and pointer years. Furthermore, this study was aimed at investigating the inter-relationships between negative pointer years and light rings of larch.

Materials and Methods

According to the differences in climate character, the territory of Lithuania is divided into four main regions: the Seaside lowlands, the Žemaičiai uplands, the Middle lowlands and the Eastern Lithuania (Figure 1). The climatic differences in these regions are mostly determined by increasing continentality, which related to the distance from the Baltic Sea (Bukantis 1994).

For our research, 26 study plots (13 in forests and 13 in parks) were selected (Figure 1). Samples from 357 mature larch trees without visible signs of crown and stem disturbance were taken by inserting an increment borer at breast height. The biggest amount of material was collected in 2006–2011 (20 plots) and 6 plots were cored in 1985–1990 and 2004.

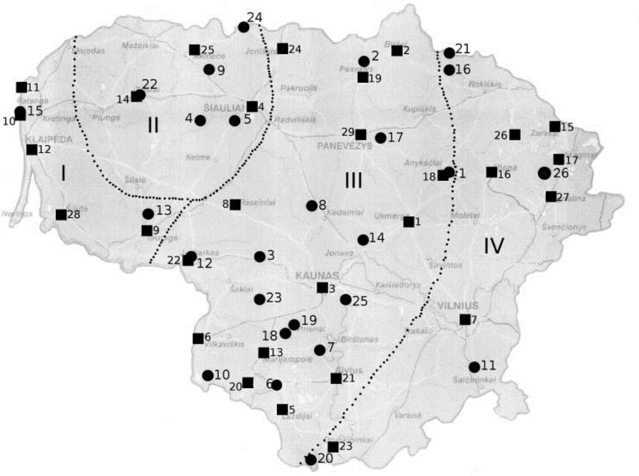

Figure 1. A network of research plots on European larch in Lithuania. ■ are research plots, ● are meteorological stations and climate regions: I is the Seaside lowlands, II is the Žemaičiai uplands, III is Middle lowlands and IV is the Eastern Lithuania

All samples were prepared by cutting with a razor blade knife and chalk powder, which provided clean and sharp surfaces. Tree-ring widths were measured using an image analysis technique. The images from the cores were taken with a flatbed scanner with 3,200 dpi resolution and then tree-ring widths from the images were measured with Cybis CooRecorder 7.1 (Cybis Elektronik & Data AB). The series were synchronized by visual comparison of ring-width graphs (Pilcher 1990) and checked against each other for false and missing rings with Cofecha 3.00P (Holmes 1983, Grissino-Mayer 2001).

The compiled tree-ring-width series were standardised to remove the age trend and other non-climatic growth variations (Chronol 6.00P); mean curves of indices for each plot were constructed and expressed population signal (EPS) was calculated. The significance level for EPS is ≥0.85. For the statistical characteristics of constructed local chronologies, please refer to Vitas and Žeimavičius (2010). In order to prove a similarity between the tree-ring pattern of larches growing in forests and parks, correlations between the local chronologies were calculated.

The mean curves of 17 research plots spanning from 1950–2003 were used as dependent variables in the analysis of response function. The chronologies from 9 plots were not used in the calculations because the last ring of 5 plots stands for 1985–1990 and the EPS of 4 site chronologies was rather low (the reliable segments of chronology did not covered 1950–2003). Air temperature and precipitation from June of the previous year to current September were used as independent variables. The calculations were performed with DendroClim2002 programme (Biondi and Waikul 2004). The obtained coefficients of the response function from 17 sites were averaged for four regions of Lithuania. In this study we used mean monthly temperatures and the sums of precipitation from the nearest meteorological station located at the distance of 3–48 km from the study plots. The stability of relationships was tested in three longest larch chronologies (Nos. 2, 7 and 20) using moving intervals from 1895–2006.

The influence of extreme climatic conditions on the radial growth of larch was evaluated using pointer year analysis (Cropper 1979). Event years for all trees in each research plot were calculated for 1900–2006, which is covered by the majority of local chronologies. The calculations were accomplished using Weiser 1.0 computer program (García-Gonzales 2001). Event year was judged as a pointer year if at least 75% of trees in the plot exhibited an event value. In this study, we have analysed pointer years if they were observed in at least 1/3 of the research plots. For the interpretation of pointer years, the data of 7 meteorological stations having longest records were used (Figure 1): Klaipėda (No. 12), Šilutė (No. 28), Telšiai (No. 14), Kaunas (No. 3), Panevėžys (No. 29), Utena (No. 16) and Vilnius (No. 7). Climate extremes were judged if the differences of air temperature or precipitation from the long-term mean exceed the standard deviation (Bukantis 1998).

Therefore, to assess the interconnection between light rings and sharp decreases in tree-ring width of larch, negative pointer years of larch were compared with corresponding ring widths of Norway spruce, which is a non-host species to larch bud-moth (*Zeiraphera diniana* Gn.).

Results

The characteristics of constructed local chronologies are presented in Table 1. The longest chronology spans from 1850–2006 with the oldest tree being 157 years old. Because of high similarity among tree-ring series, the reliable segment of chronologies defined by EPS ≥ 0.85 is comparatively long for the majority of chronologies (Table 1). Correlation coefficients have confirmed the similar growth dynamics of larch growing in parks, forests and between parks and forests (*r* = 0.46, 0.44 and 0.42, respectively) (Table 2).

Table 1. Characteristics of the local chronologies of European larch in Lithuania and meteorological stations. The numbers of plots used in the analysis of the response function are shown in bold; N/A is span with EPS ≥ 0.85 not available

No. of chronology	**No. of trees**	**Span**	**Span with EPS ≥ 0.85**	**No. of meteorological station**
1	12	1933–2006	1950–2006	1, 18
2	21	1894–2006	1894–2006	2, 19
3	2	1876–2006	N/A	3
4	18	1869–2006	1877–2006	4
5	8	1891–2006	1913–2006	4
6	25	1862–2006	1874–2006	5, 13, 20
7	24	1850–2006	1857–2006	3, 21
8	20	1861–1987	1867–1987	1
9	6	1913–1989	N/A	4, 24, 25
10	24	1867–2006	1884–2006	6, 20
11	11	1903–2007	1919–2006	7
12	17	1896–2006	1901–2006	8, 9, 22
13	4	1893–2006	1951–2006	8, 9
14	9	1913–1985	N/A	1
15	3	1916–2006	1947–2006	10, 11, 12
16	3	1899–1900	1903–1990	2
17	8	1892–1987	1920–1987	29
18	33	1912–2003	1922–2003	3, 13
19	22	1865–2006	1870–2006	3, 13
20	20	1862–2006	1865–2006	5, 23
21	10	1891–2006	1900–2006	2
22	5	1885–2008	N/A	14
23	20	1858–2006	1864–2006	3
24	18	1899–2006	1904–2006	4, 24, 25
25	7	1885–2006	1898–2006	3
26	6	1877–2011	N/A	15, 16, 17, 26, 27

Coefficients of the response function between the radial growth of larch and air temperature for different regions of Lithuania are shown in Figure 2. Response function demonstrated that the radial growth of larch is inversely related to air temperature in previous June – September. Relationships in previous July (Figure 2) are statistically significant in all regions and stable from 1895–2006 (Figure 3). The influence of air temperature in current April and May is positive (Figure 2) and increasing from 1895–2006 (Figure 3). The relationships in January are higher in the Eastern Lithuania indicating a higher negative influence of winter colds in comparison to other regions (Figure 2). However, coefficients are decreasing (Figure 3) demonstrating the declining negative influence of winter colds on the radial growth of larch.

The influence of precipitation on the radial growth of larch across Lithuania is usually positive but more variable than the relationships with air temperature (Figure 4). A positive influence of precipitation in previous June (Figure 4) is the highest and significant in the Middle lowlands and the Eastern Lithuania. The relationships are increasing from 1895–2006 (Figure 5). A positive, significant (Figure 4) and increasing influence of precipitation in the current June (Figure 5) were observed in the region of the Middle lowlands.

9 negative and 10 positive pointer years were defined for the radial growth of larch in Lithuania. The percentage of trees, demonstrating negative and positive pointer years altogether with extremes of air temperature and precipitation is presented in Table 3. Climate extremes were judged if the differences from the long-term mean exceed the standard deviation.

Pointer years repeated successively indicate the high variability and sensitivity of tree-ring-width series in larch. The decrease of growth lasted for two years in 1920–1921 and 1940–1941. The wide-narrow

Table 2. Correlation matrices between the tree-ring chronologies of larch; research plots located in parks are marked in bold

No	1	2	**3**	4	5	6	7	**8**	**9**	10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	18	19	20	21	**22**	23	**24**	25
2	0.43																								
3	0.22	0.35																							
4	0.21	0.40	0.13																						
5	0.19	0.41	0.57	0.50																					
6	0.51	0.53	0.22	0.36	0.31																				
7	0.32	0.54	0.19	0.53	0.35	0.48																			
8	0.39	0.78	0.41	0.45	0.55	0.54	0.49																		
9	0.30	0.59	0.16	0.35	0.23	0.30	0.31	0.56																	
10	0.48	0.49	0.18	0.34	0.28	0.67	0.41	0.53	0.46																
11	0.43	0.43	0.23	0.34	0.39	0.43	0.27	0.49	0.36	0.41															
12	0.41	0.58	0.32	0.63	0.63	0.43	0.54	0.78	0.57	0.51	0.58														
13	0.30	0.57	0.28	0.55	0.56	0.47	0.44	0.66	0.42	0.43	0.62	0.74													
14	0.30	0.33	0.52	0.51	0.52	0.38	0.36	0.42	0.24	0.35	0.57	0.43	0.38												
15	0.21	0.30	0.25	0.37	0.44	0.19	0.25	0.31	0.35	0.29	0.31	0.46	0.37	0.35											
16	0.32	0.72	0.51	0.33	0.57	0.54	0.40	0.73	0.49	0.50	0.31	0.62	0.44	0.35	0.27										
17	0.39	0.70	0.46	0.38	0.54	0.46	0.35	0.78	0.41	0.35	0.65	0.70	0.62	0.51	0.39	0.64									
18	0.22	0.40	0.32	0.15	0.36	0.43	0.25	0.49	0.28	0.54	0.39	0.31	0.37	0.54	0.10	0.38	0.39								
19	0.40	0.69	0.43	0.36	0.35	0.51	0.50	0.70	0.52	0.56	0.51	0.61	0.41	0.52	0.27	0.72	0.64	0.55							
20	0.25	0.22	0.20	0.26	0.35	0.49	0.35	0.37	0.08	0.54	0.34	0.37	0.23	0.42	0.03	0.29	0.24	0.47	0.36						
21	0.39	0.60	0.46	0.26	0.58	0.55	0.38	0.70	0.38	0.49	0.42	0.57	0.45	0.40	0.23	0.79	0.70	0.47	0.59	0.42					
22	0.20	0.36	0.17	0.36	0.36	0.41	0.32	0.50	0.29	0.46	0.21	0.42	0.42	0.30	0.28	0.37	0.36	0.40	0.32	0.26	0.47				
23	0.23	0.50	0.28	0.43	0.57	0.59	0.43	0.64	0.40	0.60	0.47	0.62	0.58	0.48	0.22	0.59	0.55	0.49	0.58	0.65	0.65	0.36			
24	0.22	0.74	0.32	0.59	0.63	0.38	0.57	0.75	0.49	0.38	0.48	0.71	0.68	0.39	0.42	0.56	0.68	0.30	0.58	0.34	0.61	0.42	0.61		
25	0.35	0.44	0.36	0.33	0.31	0.49	0.38	0.55	0.45	0.62	0.46	0.50	0.36	0.46	0.21	0.43	0.46	0.52	0.63	0.50	0.41	0.42	0.65	0.41	
26	0.24	0.56	0.30	0.31	0.38	0.57	0.31	0.71	0.44	0.43	0.56	0.55	0.49	0.51	0.31	0.54	0.70	0.51	0.53	0.33	0.65	0.35	0.51	0.50	0.44

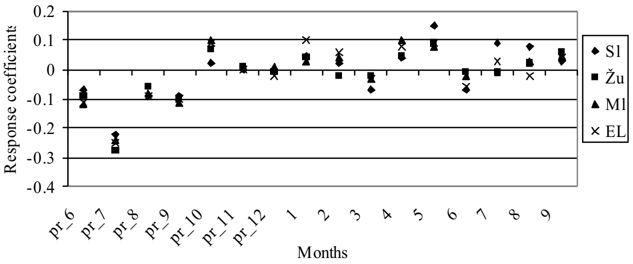

Figure 2. Average coefficients of response function between the radial growth of larch and air temperature in different regions of Lithuania; *Sl* is the Seaside lowlands, *Žu* is the Žemaičiai uplands, *Ml* is the Middle lowlands, *EL* is the Eastern Lithuania, *pr* is previous year

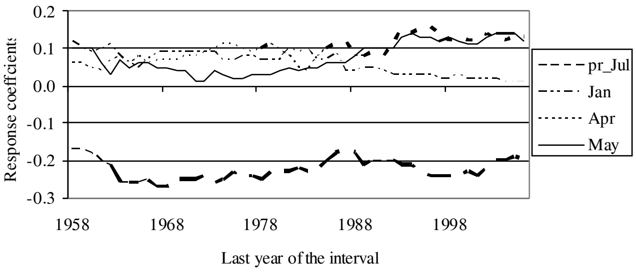

Figure 3. The moving intervals of response coefficients (averages) between the radial growth of larch in three sites and previous July (pr_Jul), current January (Jan), April (Apr) and May (May) air temperature. Significant coefficients are shown in bold

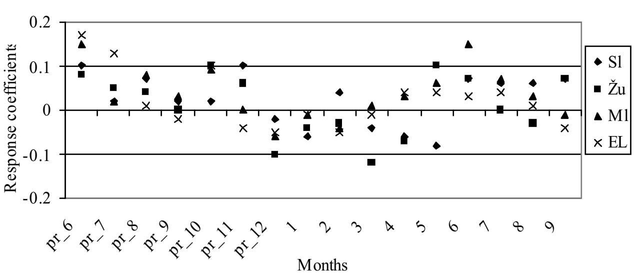

Figure 4. Average coefficients of response function between the radial growth of larch and precipitation in different regions of Lithuania; *Sl* is the Seaside lowlands, *Žu* is the Žemaičiai uplands, *Ml* is the Middle lowlands, *EL* is the Eastern Lithuania, *pr* is previous year

tree rings repeated alternatively in 1963–1964, 1983–1984, 2000–2001 and 2005–2006.

The majority of negative pointers years was provoked by droughts in spring and summer (1900, 1915, 1927, 1940, 1941, 1964, 1967, 1969, 1976, 1992 and 2006). The sharp growth decreases in 1933, 1952 and 1954 were triggered by anomalous colds in winter and spring. In 1915, 1940, 1941, 1964, 1967 and 1969, droughts altogether with colds were recorded (Table 3). The growth decrease in 1920, 1921, 1984, 1995 and 2000 cannot be explained by climatic extremes.

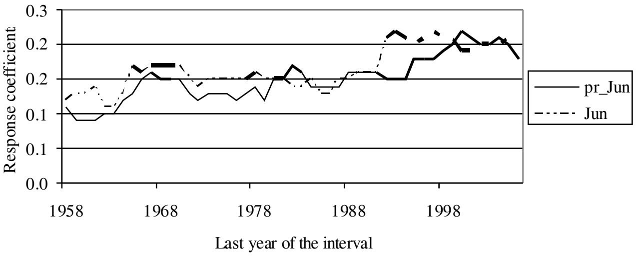

Figure 5. The moving intervals of response coefficients (averages) between the radial growth of larch in three sites and precipitation of previous June (pr_Jun) and current June (Jun). Significant coefficients are shown in bold

Obviously, the arid periods lasting for several months as well as droughts of one-month duration may trigger the sharp decrease in tree-ring widths of larch. For example, a sharp decrease in 1967 was caused by a dry July, and in 1992 a long-lasting drought was recorded (Table 3). Extremely cold winter and spring conditions might be considered as indirect triggers of pointer years because only three pointers years could be exclusively attributed to the influence of cold winters (Table 3). Because of globally rising air temperatures, extreme winter and spring colds were not observed after the negative pointer year in 1969.

Warm winters and springs caused positive pointer years in 1910, 1936, 1957, 1963, 1975, 1983, 1988, 1997, 2001 and 2005. In 1910, 1957, 1975, 1983, 1988, 1997, 2001 and 2005, abundant precipitation has felt in springs and summers. The both extremes occured (were in operation) in 1910, 1957, 1975, 1983, 1988, 1997, 2001 and 2005 (Table 3). Hence, warm conditions in winter and spring as well as adequate supply of moisture favour the radial growth of larch in Lithuania.

Analysis of the spatial differences of pointer years (data not provided in this article) indicated that drought intensity in June–July was the most frequent cause of spatial differences. This is because the scattered showers are typical for July in Lithuania. Droughts in August as well as colds in March and other months are of secondary importance. The regional differences during positive pointer years were mostly determined by different amount of precipitation in summer and temperature contrasts in March.

During the majority of negative pointer years of larch, a significant decrease in radial growth of spruce was also observed. However, in 1927 an equal number of spruce trees (32%) showed tendencies of growth increase and decrease. In 1933, 1940 and 1995, the growth of more spruce trees increased rather than decreased (Figure 6). Hence, it indicates that these pointer years in larch may contain another ecological signal.

Table 3. Pointer years for European larch radial growth and extremes of air temperature (in numerator) and precipitation (denominator) when their differences from the mean exceed the standard deviation; Z is % of trees with growth decrease (-) and increase (+), I-VIII are months, NR is no climatic extremes recorded

Years	Z (%)	Extremes of air temperature (±°C) and precipitation (±mm)							
		I	II	III	IV	V	VI	VII	VIII
1900 (-)	75	NR	NR	NR	NR	-2.0	NR	NR	**+1.8**
		+27	+16	NR	NR	-30	NR	-55	**-52**
1910 (+)	64	NR	+4.3	NR	+2.0	+2.5	+2.1	NR	**-1.6**
		NR	NR	-24	NR	NR	+66	+57	**+75**
1915 (-)	70	NR	NR	-3.7	NR	NR	NR	NR	**NR**
		NR	+23	+23	-19	NR	-52	NR	**-62**
1920 (-)	60	NR	NR	+3.2	+5.1	+2.8	-1.9	+1.9	**NR**
		+23	NR	NR	NR	NR	NR	NR	**NR**
1921 (-)	47	NR	NR	+5.0	+3.0	+3.0	NR	-2.0	**NR**
		+44	-18	NR	NR	NR	NR	NR	**NR**
1927 (-)	74	NR	NR	+2.7	NR	-3.7	-1.7	+2.2	**NR**
		-25	-26	+39	+34	NR	+33	-53	**NR**
1933 (-)	78	-3.7	NR	NR	-2.1	-2.3	NR	NR	**-1.8**
		-22	+25	NR	NR	+44	+60	NR	**NR**
1936 (+)	66	+4.8	NR	+2.8	NR	+2.0	+2.6	+2.1	**NR**
		NR	NR	NR	NR	NR	-34	NR	**NR**
1940 (-)	74	-8.6	-9.0	-3.8	-2.1	NR	+2.2	NR	**-1.6**
		NR	NR	+24	-25	NR	-45	+82	**NR**
1941 (-)	70	-7.9	NR	NR	-3.6	-3.0	NR	+2.2	**NR**
		NR	-23	NR	NR	-34	-37	-35	**NR**
1952 (-)	63	+3.8	NR	-7.2	+2.0	-2.7	-1.9	NR	**NR**
		NR	NR	-36	NR	NR	NR	NR	**NR**
1954 (-)	74	-5.0	-8.0	NR	-2.8	NR	+1.9	NR	**NR**
		NR	-25	-26	NR	NR	NR	+68	**+96**
1957 (+)	71	NR	+4.6	NR	NR	NR	NR	NR	**NR**
		NR	+24	-22	-22	NR	NR	NR	**+54**
1963 (+)	76	-6.6	-4.8	-4.5	NR	+3.1	NR	NR	**+2.0**
		-28	NR	NR	-25	NR	NR	-45	**NR**
1964 (-)	71	NR	-4.2	-3.9	NR	NR	+2.4	NR	**-1.5**
		-28	NR	-26	-32	-31	-46	-62	**NR**
1967 (-)	61	-4.4	NR	+3.1	NR	+2.0	NR	NR	**NR**
		NR	NR	+26	NR	NR	NR	-54	**+71**
1969 (-)	45	-5.4	NR	-3.6	NR	NR	NR	NR	**NR**
		-27	NR	-26	+42	+41	-53	-46	**NR**
1975 (+)	65	+5.1	+3.8	+3.0	NR	+2.4	NR	NR	**+1.6**
		+30	-20	NR	+36	NR	-45	NR	**-74**
1976 (-)	75	NR	NR	NR	NR	NR	-2.4	NR	**-1.6**
		+47	-25	NR	NR	NR	NR	-56	**NR**
1983 (+)	55	+5.1	NR	NR	NR	+2.5	NR	NR	**+1.5**
		+54	NR	+54	+42	+38	NR	-44	**-62**
1984 (-)	71	NR	NR	NR	+2.2	+2.2	-2.1	-2.2	**NR**
		+62	NR	-22	-25	+52	+49	+43	**NR**
1988 (+)	65	NR	NR	NR	NR	+2.1	+2.4	NR	**NR**
		NR	NR	+22	NR	-24	NR	+114	**+55**
1992 (-)	72	+4.3	+4.2	+3.0	NR	NR	+2.2	NR	**+2.0**
		-32	+20	+19	+34	NR	-46	-54	**NR**
1995 (-)	78	NR	+5.8	+2.7	NR	NR	+2.1	NR	**NR**
		+34	+81	+40	NR	NR	+60	NR	**NR**
1997 (+)	61	NR	+4.5	NR	-2.3	NR	NR	NR	**+2.9**
		-26	NR	NR	+45	+36	NR	-58	**-75**
2000 (-)	70	NR	+4.8	NR	+5.1	NR	NR	NR	**NR**
		NR	+29	+32	-23	NR	NR	+91	**NR**
2001 (+)	74	NR	NR	NR	+2.3	NR	NR	+3.4	**NR**
		NR	+28	NR	NR	-26	+70	+65	**NR**
2005 (+)	88	+4.2	NR	-3.2	NR	NR	NR	+1.9	**NR**
		+29	NR	NR	NR	+100	NR	NR	**+114**
2006 (-)	**85**	**NR**	**NR**	**NR**	**NR**	**NR**	**+1.7**	**+3.4**	**+1.8**
		-28	**NR**	**NR**	**NR**	**NR**	**+45**	**-65**	**+69**

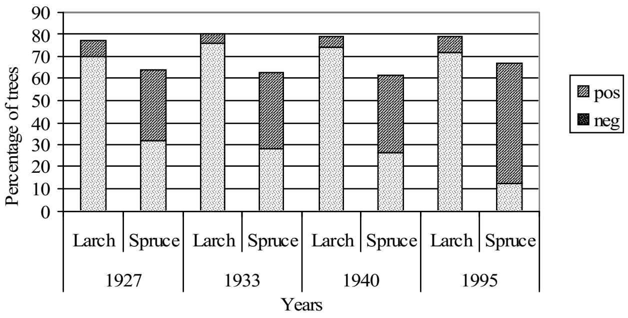

Figure 6. Negative pointer years of European larch tentatively containing another ecological signal and corresponding percentages of European larch and Norway spruce trees indicating a radial growth decrease

Discussion and conclusions

Since the early dendrochronological works in Lithuania, local conifers were the most preferred research object. This was determined by easy visible ring boundaries and the prevalence of coniferous tree species in Lithuanian forests (Битвинскас 1974). Due to a limited number of available sites and usually a small amount of trees in each site, investigations of growth variations and relationships with climate in time and space are more challenging (Vitas and Žeimavičius 2006) in comparison to native conifers (Vitas 2002).

Because European larch is a native species in the Alps, the majority of studies on larch have been conducted in alpine regions. For example, Serre (1978) in French Alps explained narrow rings in larch with a wet and cold previous autumn and winter, abundant precipitation in June–July, high temperature in March–May and cool-wet summers. This is in accordance with the investigation by Büntgen et al. (2008). Based on a wide network of larch chronologies, they concluded that summer temperatures are positively correlated with larch tree-ring widths. Oleksyn and Fritts (1991) in the south-west of Poland observed that the growth of larch is directly related to precipitation in May–June and temperatures in previous June–August had an inverse effect. The most recent study conducted in lowland Poland showed a negative influence of air temperature in previous July–September, positive in previous October, current March and May. Precipitation has a positive influence (previous May, July–September and May–July of current year) (Koprowski 2012). This is in agreement with our observations, e.g. negative impact of air temperature in previous summer, positive in current spring as well as positive influence of precipitation in June of current vegetation season (Figures 2, 4).

Results of several studies on larch in Lithuania contradict each other because the chronologies might potentially contain dating errors, studies were based on a limited number of sites and trees and different methods were used assessing the climate/growth relationships: (i) direct relationship with cool and humid summers (Kaminskaitė 2002, Pukienė and Bitvinskas 2000), (ii) positive influence of cold winters (Pukienė and Bitvinskas 2000), (iii) inverse relationship with precipitation and air temperature in March (Kaselytė 2003). The radial growth relationships of larch to air temperature and precipitation in Lithuania are much more complex than those of Norway spruce (Koprowski and Vitas 2010, Läänelaid and Eckstein 2012) and Scots pine (Vitas 2006). Both native conifers are directly responsive to air temperature in March–April and precipitation in June. In contrast, larch demonstrates highest negative relationships with air temperature in previous July (Figure 2). It is noteworthy that direct relationships between the growth of larch and air temperature in April and May (0.08 and 0.09) are much lower than in spruce (0.16 and 0.08). Similarly, larch growth shows lower relationships with precipitation in June in comparison to spruce (0.10 and 0.22, respectively). Analysis of moving intervals showed an increasing importance of precipitation of June (Figure 5), which might be explained by more frequent and longer-lasting droughts during the last decades (Šabūnaitė and Vitas 2013).

The sharp decreases in the radial growth of larch in Lithuania for the majority of pointer years during the last century were provoked by hot and dry summers. Colds in winter and spring may be considered as of secondary importance (Table 3). This is in accordance with Oleksyn and Fritts (1991) and Koprowski (2012) who found that larch radial growth is directly related to summer precipitation, whereas colds in spring and summer play only a secondary role (Oleksyn and Fritts 1991). European larch in Lithuania is considered tolerant to winter colds as confirmed by Pukienė and Bitvinskas (2000). This is in accordance to Kaselytė (2003), who described the lower sensitivity of larch to winter colds in comparison to Scots pine.

Our research on larch tree-ring relationships with climate is the first one in Lithuania utilizing a wide network of research plots. The long-term relationship between the radial growth of larch and climate in Lithuania is more complex in comparison to native conifers because European larch shows inverse links with air temperature in previous summers (Figure 2). Analysis of pointer years has shown that sharp decreases in the radial growth of larch are usually triggered by summer droughts and increases are favoured by higher air temperature as well as abundant precipitation in summer (Table 3).

However, negative pointer years of European larch do not always contain a pure climatic signal. According to Baltensweiler et al. (2008), the defoliation of larch induces an immediate reduction in latewood and a significant decrease in ring width in the following growing season. On the other hand, ponderosa moth outbreaks are related to drought events (Pohl et al. 2006) because drought increases susceptibility to defoliation by insects (Mattson and Hack 1987). However, larch pests and diseases are not comprehensively investigated in Lithuania.

A. Läänelaid (2007) documented a phenomenon of light rings in larch growth in Estonia. The similar character of light rings in larch (Figure 7) was described in Lithuania by Vitas and Žeimavičius (2010). Although, positive pointer years in larch were explained

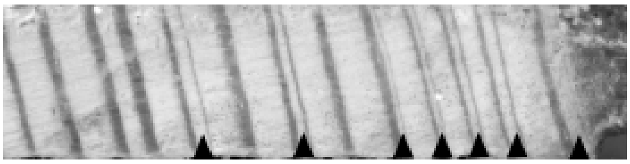

Figure 7. A core No. 13 from research plot No. 6 with typical light rings in larch. The black arrows (from left to right) correspond to 1992, 1995, 1998, 2000, 2002, 2004 and 2006. The last ring (2007) is not formed completely

for all years by climatic extremes in this study, it was not possible to explain the cause of several (1920, 1921, 1984, 1995, 2000) negative pointer years. Meanwhile, the cause of negative pointer years usually could be explained more easily in comparison to positive pointer years (Vitas 2002).

Several pointer years repeated alternatively, when a narrow ring is followed by a wide ring, e.g. in 1963–1964, 1983–1984, 2000–2001 and 2005–2006 (Table 3). It is evident that negative pointer years of larch in Lithuania are related to the occurrence of light rings (Vitas and Žeimavičius 2010). During the majority of detected negative pointer years, a significant decrease in radial growth of spruce was also observed. However, in 1927, 1933, 1940 and 1995, the majority of spruce trees indicated a growth increase rather than a decrease (Figure 6). According to Büntgen et al. (2009), if host trees (European larch) show a negative pointer year, while non-host trees show a growth release in the same year, this demonstrates that the tentative cause of growth reduction perhaps was of non-climatic nature. Therefore, it suggests that the aforementioned pointer years in larch may contain an ecological signal rather than climatic one.

It is noteworthy that the cause and ecological implication of light rings of larch in Lithuania as well as their spatial distribution still require a serious dedicated study. To solve this task, it is necessary to develop a statistical methodology for detection of light rings based on earlywood / latewood ratio to perform the spatio-temporal analysis of light rings and to expand the collaboration with researchers (scientists) in the neighbouring countries.

Acknowledgements

The author expresses kindest respect to late Dr. Kęstutis Žeimavičius (1955–2011) who allowed to use his own data and participated during the fieldwork.

References

Baltensweiler, W., Weber, U.M. and Cherubini, P. 2008. Tracing the influence of larch-bud-moth insect outbreaks and weather conditions on larch tree-ring growth in Engadine (Switzerland). *Oikos* 117: 161–172.

Biondi, F. and Waikul, K. 2004. DendroClim2002: A C++ program for statistical calibration of climate signals in tree-ring chronologies. *Computers and Geosciences* 30: 303–311.

Bukantis, A. 1994. Lietuvos klimatas [Climate of Lithuania]. VU leidykla, Vilnius, 187 pp. (in Lithuanian).

Bukantis, A. 1998. Neįprasti gamtos reiškiniai Lietuvos žemėse XI–XX amžiuose [The unusual natural phenomena on the territory of Lithuania in the 11th – 20th centuries]. Geografijos institutas, Vilnius, 197 pp. (in Lithuanian).

Büntgen, U., Frank, D., Liebhold, A., Johnson, D., Carrer, M., Urbinati, C., Grabner, M., Nicolussi, K., Levanic, T. and Esper, J. 2009. Three centuries of insect outbreaks across the European Alps. *New Phytologist* 182: 929–941.

Büntgen, U., Frank, D., Wilson, R., Carrer, M., Urbinati, C. and Esper, J. 2008. Testing for tree-ring divergence in the European Alps. *Global Climate Biology* 14: 2443–2453.

Cropper, J.P. 1979. Tree-ring skeleton plotting by computer. *Tree-Ring Bulletin* 39: 47–60.

Filion, L., Payette, S., Gauthier, L. and Boutin, Y. 1986. Light rings in subarctic conifers as a dendrochronological tool. *Quaternary Research* 26: 272–279.

García-González, I. 2001. Weiser: a computer program to identify event and pointer years in dendrochronological series. *Dendrochronologia* 19(2): 239–244.

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

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* 43: 69–78.

Huesken, W. 1993. Dendroklimatologische Untersuchungen an der Lärche (*Larix decidua*) in den Pragser Dolomiten (Südtirol/Italien) [Dendroclimatological investigations on larch (*Larix decidua*) in the Pragser Dolomites (south Tirol, Italy)]. *Wetter und Leben* 45(4): 17–27 (in German).

Januškevičius, L. 2004. Lietuvos parkai [Parks of Lithuania]. Lututė, Kaunas, 488 pp. (in Lithuanian).

Kaminskaitė, G. 2002. Lenkinio maumedžio (*Larix polonica* Racib.) augimas ir būklė Degsnės maumedyne [The growth and state of European larch (*Larix polonica* Racib.) in the Degsnė larch stand]. Bachelor thesis. VMU, Kaunas, 90 pp. (in Lithuanian).

Kaselytė, A. 2003. Pietų Lietuvoje augančių maumedžių ir pušų dendroklimatochronologiniai tyrimai [Dendroclimatochronological investigations on larch and pine growing in the South Lithuania]. Master thesis. VMU, Kaunas, 53 pp. (in Lithuanian).

Koprowski, M. 2012. Long-term increase of March temperature has no negative impact on tree rings of European larch (*Larix decidua*) in lowland Poland. *Trees – Structure and Function* 26: 1895–1903.

Koprowski, M. and Vitas, A. 2010. Growth/climate relationships in tree-ring widths of *Picea abies* in Lithuania and Poland. In: R. Przybylak, J. Majorowicz, R. Brázdil and M. Kejna (Editors), The Polish climate in the European context. Springer, Dordrecht, Heidelberg, London, New York, p. 327–340.

Kress, A., Saurer, M., Büntgen, U., Treydte, K.S., Bugmann, H. and Siegwolf, R.T.W. 2009. Summer temperature dependency of larch budmoth outbreaks revealed by Alpine tree-ring isotope chronologies. *Oecologia* 160: 353–365.

Läänelaid, A. 2007. Light rings in larches: searching for causes. Thesis of the Int. Conf. "Trace 2007". University of Latvia, Rīga, p. 38–39.

Läänelaid, A. and Eckstein, D. 2012. Norway Spruce in Estonia reflects the early summer weather in its tree-ring widths. *Baltic Forestry* 18 (2): 194–204.

Mattson, W.J. and Hack, R.A. 1987. The role of drought in outbreaks of plant-eating insects. *Bioscience* 37: 110–118.

Oleksyn, J. and Fritts, H.C. 1991. Influence of climatic factors upon tree rings of *Larix decidua* and *L. decidua* × *L. kaempferi* from Pulawy, Poland. *Trees – Structure and Function* 5(2): 75–82.

Pilcher, J.R. 1990. Sample preparation, cross-dating, and measurement. In: E. Cook and L.A. Kairiukstis (Editors), Methods of dendrochronology: applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht, p. 40–51.

Pohl, K.A., Hadley, K.S. and Arabas, K.B. 2006. Decoupling tree-ring signatures of climate variation, fire, and insect outbreaks in Central Oregon. *Tree-Ring Research* 62(2): 37–50.

Polster, H. 1967. Transpiration. In: L.K. Polster and H.J. Fiedler (Editors), Gehölzphysiologie. Fischer, Jena, p. 163–183.

Pukienė, R. and Bitvinskas, T. 2000. Europinio maumedžio (*Larix decidua* Mill.) radialinio prieaugio kaitą lemiantys aplinkos veiksniai [Environmental factors influencing European larch (*Larix decidua* Mill.) radial growth variations]. *Dendrologia Lithuaniae* 5: 72–77 (in Lithuanian).

Serre, F. 1978. The dendroclimatological value of the European larch (*Larix decidua* Mill.) in the French Maritime Alps. *Tree-Ring Bulletin* 38: 25–34.

Šabūnaitė, J. and Vitas, A. 2013. Rododendrų (*Rhododendron*) genties augalų vaisių ir sėklų tyrimai VDU Kauno botanikos sode [Assessment of fruits and seeds of rhododendron (*Rhododendron* L.) genus plants in Kaunas Botanical Garden of Vytautas Magnus University]. *Optimization of Ornamental and Garden Plant Assortment, Technologies and Environment* 4(9): 136–140 (in Lithuanian).

Vitas, A. 2002. Klimato veiksnių įtaka paprastosios eglės (*Picea abies* (L.) Karsten) radialiajam prieaugiui [Impact of climate factors on the radial increment of Norway Spruce (*Picea abies* (L.) Karsten)]. Doctoral dissertation. VMU, Kaunas, 114 pp. (in Lithuanian).

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

Vitas, A. and Žeimavičius, K. 2006. Trends of decline of Douglas fir in Lithuania: dendroclimatological approach. *Baltic Forestry* 12(2): 200–208.

Vitas, A. and Žeimavičius, K. 2010. Regional tree-ring chronology of European larch (*Larix decidua* Mill.) in Lithuania. *Baltic Forestry* 16(2): 187–193.

Vitas, A. and Žeimavičius, K. 2011. Influence of climatic factors on tree-ring widths of European larch in Lithuania. In: Abst. of Int. Conf. "Eurodendro 2011". WSL, Birmensdorf: 116.

Битвинскас, Т. 1974. Дендроклиматические исследования [Dendroclimatic investigations]. Gidrometeoizdat, Leningrad, 172 pp. (in Russian).

Received 13 May 2014
Accepted 21 October 2014