Regional Tree-Ring Chronology of European Larch (*Larix Decidua* Mill.) in Lithuania

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Abstract

A dendrochronological study of European larch (*Larix decidua* Mill.) has been carried out in Lithuania and a regional tree-ring chronology constructed. Our investigation, based on 25 experimental plots (351 trees), demonstrates that a similar growth pattern is characteristic of larch growing across Lithuania. The radial growth of larch is characterized by a high mean sensitivity (on average 0.35±0.01) and the occurrence of light rings. The compiled regional tree-ring chronology ranges from 1850 to 2008. The analysis of signature years has revealed that the formation of narrow rings is linked to hot/dry summers and of wide rings to warm winters and springs. The tree-ring patterns of larch and Norway spruce, growing in a mixed stand, are similar (correlations from 0.26 to 0.51, p=0.01), while the similarity with Scots pine is much lower (correlations from 0.16 to 0.20, p from 0.03 to 0.13).

Key words: European larch, Lithuania, regional tree-ring chronology, tree-ring widths, signature years, climate.

Introduction

Replicated tree-ring data at the tree level as well as site and regional level is a unique characteristic among the various proxy archives (Frank et al. 2009). Tree-ring widths, wood density, and signature years provide information on environmental changes with annual resolution during the whole lifetime of trees (Kaennel and Schweingruber 1995, Schweingrubrer et al. 1990).

The radial growth of native coniferous species (Norway spruce and Scots pine) has been comprehensively investigated in Lithuania, for example, by Vitas (2002) and Битвинскас (1974). The radial growth of introduced coniferous species, except of Douglas fir, is explored poorly (Vitas and Žeimavičius 2006).

European larch is native in the European mountains – the Alps, Carpathians, and Sudetes (Navasaitis 2004). Although larch trees were planted as early as the beginning of 19th c. (Januškevičius 2004), little information is available about their growth and on the influence of climatic factors on tree-ring formation. The ecology of larch is investigated in many studies (for example, Schober 1949, Jankauskas 1954), but there is little information on the effects of environmental factors on the radial growth in Lithuania. Most studies on tree rings of larch have been conducted in the Alps at the upper forest limits (Büntgen et al. 2008, Kress et al. 2009, Serre 1978). The investigations in the Alps have shown that tree rings are suitable for dendrochronological investigations: the trees are fairly old and tree-ring boundaries are clearly visible (Büntgen et al. 2008, Serre 1978).

The tree-ring widths of European larch have been investigated in several studies in Lithuania (Kaminskaitė 2002, Kaselytė 2003, Pukienė and Bitvinskas 2000). However, the results are based on one or a few research plots and they are controversial. Therefore, there is an urgent need to assess the radial growth of European larch over a wide network of experimental plots in Lithuania.

The aims of this study were to (1) establish such a network including all known growing places of larch in Lithuania, (2) construct a regional tree-ring chronology of larch and (3) assess the tree-ring growth dynamics and compare it with other coniferous species (Scots pine and Norway spruce) at the same stands.

Materials and methods

For our research, 25 experimental plots were selected: 13 plots are located in forests and 12 in city parks (Figure 1, Table 1). In total 351 mature larch trees were cored at breast height and samples were taken for tree-ring measurements. The majority of trees were cored in 2007, thus the last ring stands for 2006. Five plots were investigated earlier – the last rings are from 1985-1990. We have also cored 10 to 15 spruces and pines in mixed larch stands to understand the differences in growth dynamics among these coniferous species. Spruces were cored in Ąžuolpamūšė, Gražiškiai, Selema, and Suvainiškis and pines in Ąžuolpamūšė, Sirguškė, Suvainiškis, and Žigla.

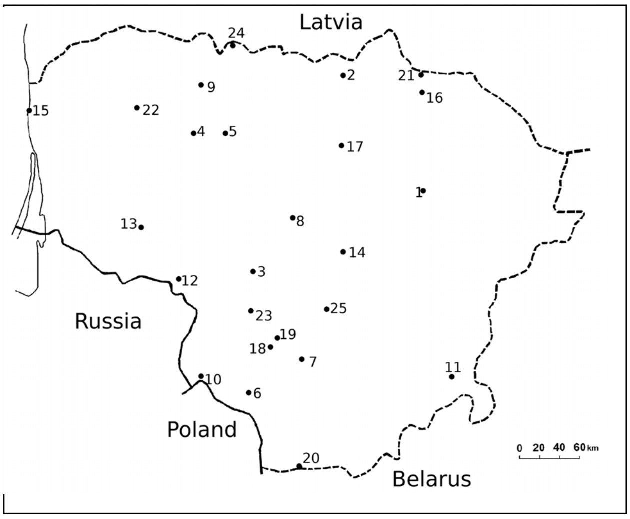

Figure 1. The location of the experimental plots of European larch in Lithuania. The number refers to toponymes in Table 1

Table 1. Characteristics of experimental plots for European larch in Lithuania

No	*Plot*	*Site*	*Geographical coordinates*		*Average altitude*	*Number of trees*
			Lat. (North)	*Long. (East)*		
1	Anykščiai	f	55º 24’ 42”	25º 06’ 15”	100	12
2	Ąžuolpamūšė	f	56º 06’ 16”	24º 28’ 32”	41	21
3	Belvederis	p	55º 04’ 48”	23º 23’ 24”	60	2
4	Beržėnai	f	55º 50’ 24”	22º 49’ 07”	104	18
5	Bubiai	f	55º 50’ 29”	23º 04’ 46”	162	9
6	Bukta	f	54º 24’ 17”	23º 27’ 01”	139	25
7	Degsnė	f	54º 34’ 06”	23º 52’ 27”	94	24
8	Dotnuva	p	55º 23’ 41”	23º 51’ 30”	63	20
9	Eglesiai	p	56º 10’ 34”	22º 49’ 20”	90	6
10	Gražiškiai	f	54º 24’ 08”	22º 59’ 20”	130	24
11	Jašiūnai	p	54º 26’ 00”	25º 17’ 40”	155	11
12	Jurbarkas	p	55º 04’ 42”	22º 45’ 14”	55	17
13	Lomiai	p	55º 22’ 25”	22º 25’ 12”	64	4
14	Markutiškiai	p	55º 08’ 22”	24º 23’ 49”	73	9
15	Palanga	p	55º 54’ 22”	21º 03’ 24”	11	3
16	Panemunis	p	56º 03’ 47”	25º 17’ 20”	86	3
17	Panevėžys	p	55º 39’ 20”	24º 40’ 05”	51	8
18	Sasnava	f	54º 35’ 54”	23º 37’ 29”	44	33
19	Selema	f	54º 40’ 50”	23º 29’ 36”	65	22
20	Sirguškė	f	53º 56’ 25”	23º 42’ 43”	103	20
21	Suvainiškis	f	56º 07’ 56”	25º 16’ 47”	97	10
22	Telšiai	p	55º 58’ 96”	22º 15’ 55”	77	5
23	Višakio Rūda	f	54º 49’ 23”	23º 25’ 31”	64	20
24	Žagarė	p	56º 21’ 35”	26º 16’ 18”	71	18
25	Žigla	f	54º 50’ 23”	24º 11’ 09”	89	7

Site abbreviations: f - forest, p - park.

The surface of the cores was prepared by cutting with a razor blade and treated by chalk. An image analysis was applied for tree-ring widths measurement. The images from the cores were taken with flatbed scanner (Epson perfection 4990, Seiko Epson Corp., Japan) with 3200 dpi resolution, i.e. the size of a pixel is 0.008 mm. The tree-ring widths from the images were measured with Cybis CooRecorder 7.1 (Cybis Elektronik & Data AB, Sweden). The series were synchronized by visual comparison of ring-width graphs (Pilcher 1990) and checked against each other using Cofecha 3.00P (Holmes 1983, Grissino-Mayer 2001).

The mean sensitivity and standard deviation were calculated for individual tree-ring series, local and regional tree-ring chronologies. The mean sensitivity measures the year-to-year variation of ring widths and the standard deviation measures the variability of the series at all wavelengths. A high mean sensitivity and standard deviation indicate a high responsiveness of the radial growth to environmental variables.

The standardisation of the series was carried out using Chronol 6.00P program (R.L. Holmes, Tucson). The tree-ring width series of each individual tree was indexed separately. The index values were calculated as rations between the actual values and the respective values of the fitted function and then combined using biweight robust estimation of the mean into a local tree-ring chronology. The similarity between tree-ring series was measured by calculating the coefficient of correlation (Cofecha 3.00P) and applying a cluster analysis (Statistica 6, Statsoft Inc., Tulsa). For the clustering the following statistical methods were adopted: joining (tree clustering) with linkage rule (Ward’s method) and distance measure (1-Pearson r). Then, the local tree-ring chronologies were averaged into a regional tree-ring chronology.

The relationships between climatic variables and the regional tree-ring chronology of larch were evaluated using a signature year analysis. To calculate signature years, we used a method of “normalisation in a moving window” suggested by Cropper (1979) by calculating Z_i index values (Formula 1):

$$Z_i = \frac{x_i - \text{mean[window]}}{\text{stdev[window]}} \qquad (1)$$

where Z_i – index value in year i,
x_i – original value (mm) in year i,
mean [window] – arithmetic mean (mm) of the ring width within a seven-year window x_{i-3}, x_{i-2}, x_{i-1}, x_i, x_{i+1}, $x_{i+2,}$ x_{i+3}

stdev [window] – standard deviation of the ring width within a seven-year window $x_{i-3}, x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2,} x_{i+3}$

The threshold value of Z_i for negative event years (i.e. narrow tree rings) is ≤ -0.50 and for positive event years (i.e. wide tree rings) is ≥0.50. Signature years for all larch trees during 1858-2007 (this period is covered by at least ten trees) were determined. The calculations were accomplished using Weiser 1.0 computer program (Gonzales 2001). The signature years were interpreted using a compendium of unusual climatic phenomena compiled by A. Bukantis (1998).

Results

The similarity (coefficient of correlation) between the tree-ring series of larch in a plot is highly reliable ($p<0.01$) and ranges from 0.52 to 0.73. The average age of the larches is 107±1.47 years with the oldest tree being 157 years old. The average tree-ring width of all trees ranges from 0.71 to 7.37 mm (on average 2.18±0.04 mm), the mean sensitivity from 0.17 to 0.71 (on average 0.35±0.01), and the standard deviation from 0.44 to 2.95 (on average 1.38±0.03).

Table 2. Statistical characteristics of the site chronologies for European larch in Lithuania

No	Plot	Number of trees	Span of mean curve	Length of mean curve	Mean sensitivity	Standard deviation
1	Anykščiai	12	1933-2006	74	0.29	0.25
2	Ąžuolpamūšė	21	1894-2006	113	0.37	0.33
3	Belvederis	2	1876-2006	131	0.57	0.40
4	Beržėnai	18	1869-2006	138	0.22	0.23
5	Bubiai	9	1891-2006	116	0.34	0.27
6	Bukta	25	1862-2006	145	0.25	0.25
7	Degsnė	24	1850-2006	157	0.23	0.24
8	Dotnuva	20	1861-1987	127	0.30	0.25
9	Eglėsiai	6	1913-1989	77	0.28	0.25
10	Gražiškiai	24	1867-2006	140	0.19	0.19
11	Jašiūnai	11	1905-2007	105	0.23	0.22
12	Jurbarkas	17	1896-2006	111	0.34	0.29
13	Lomiai	4	1893-2006	114	0.35	0.28
14	Markutiškiai	9	1913-1985	73	0.24	0.23
15	Palanga	3	1916-2006	91	0.39	0.33
16	Panemunis	3	1899-1990	92	0.55	0.46
17	Panevėžys	8	1892-1987	96	0.45	0.31
18	Sasnava	33	1912-2003	92	0.19	0.18
19	Selema	22	1865-2006	142	0.27	0.25
20	Sirguškė	20	1862-2006	145	0.20	0.20
21	Suvainiškis	10	1891-2006	116	0.31	0.26
22	Telšiai	5	1885-2008	124	0.30	0.27
23	Višakio Rūda	20	1858-2006	149	0.20	0.18
24	Žagarė	18	1899-2006	108	0.29	0.25
25	Žigla	7	1885-2006	122	0.30	0.26

Twenty-five, 73-157 years long site chronologies of European larch were constructed. Their mean sensitivity ranges from 0.19 to 0.57 and their standard deviation from 0.18 to 0.46 (on average 0.26±0.01) (Table 2). The similarity between the site chronologies usually is statistically reliable, even if the plots are located 100-200 km apart from each other. The average correlation coefficients decrease from 0.50-0.55 to 0.30-0.40, whereas the distance increases from 50 to 200-250 km (Figure 4).

The cluster analysis of the site chronologies (Figure 2) shows that they are distributed in two clusters and three sub-clusters (IA, IB, and II). However, these clusters do not represent geographic regions (see Figure 1). Therefore, a regional tree-ring chronology representing the radial growth of larch at all investigated experimental plots was constructed.

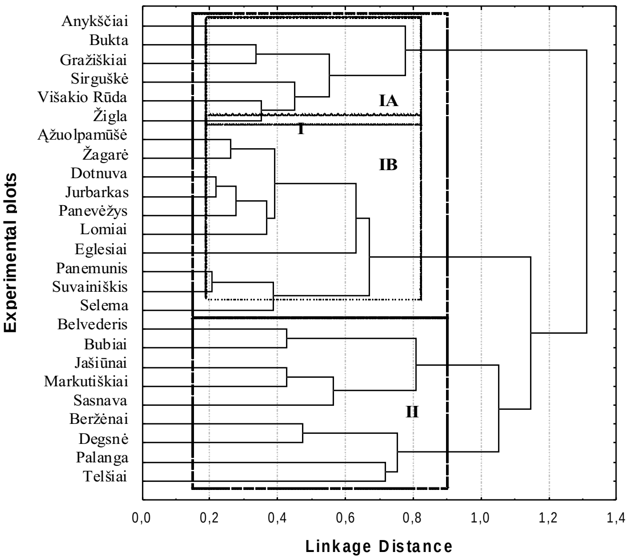

Figure 2. Cluster analysis among European larch site chronologies. I and II - clusters, IA and IB - sub-clusters

The regional tree-ring chronology, assembled from 25 site chronologies and altogether 351 trees extends from 1850 to 2008 (Table 3 and Figure 3). The reliable part of this chronology, covered by at least ten trees, runs from 1858 to 2007. Its mean sensitivity is 0.20 and its standard deviation 0.17.

The indexed chronology (Figure 3) shows a high inter-annual variation. A Fourier analysis confirms the dominance of short-term cyclic components ranging from 2 to 17years (results not shown in the article). A two-year-cycle, with a narrow ring followed by a wide ring and vice versa, is clearly visible in 1883-1889, 1900-1908, 1932-1938, 1951-1961, 1966-1973, 1979-1985, and 1997-2006.

Table 3. Regional tree-ring chronology of European larch in indices (upper value) and number of trees (lower value)

Decade	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
185	92	81	76	112	126	101	109	106	75	85
	2	2	4	5	6	7	7	9	10	10
186	119	102	108	115	121	110	106	106	61	104
	12	15	20	23	29	33	39	44	52	56
187	101	103	118	101	82	90	99	108	102	121
	66	77	80	84	90	90	92	96	102	108
188	132	95	96	98	101	72	102	98	107	90
	113	117	117	122	127	132	134	138	139	140
189	96	101	98	97	115	123	86	108	115	89
	141	145	154	157	167	171	175	179	183	188
190	80	102	96	110	99	112	101	106	103	95
	196	204	207	212	220	226	232	238	244	251
191	124	99	90	114	86	74	122	93	106	128
	253	259	262	267	272	275	277	281	282	282
192	76	89	110	90	113	114	109	74	84	123
	288	291	294	296	299	303	308	314	316	318
193	105	113	112	77	107	102	122	87	101	90
	318	319	319	321	321	322	324	325	325	326
194	68	71	85	119	122	94	120	96	86	128
	326	327	328	328	328	329	329	330	331	331
195	119	117	82	113	67	89	75	116	81	89
	333	335	336	338	339	341	342	343	345	346
196	83	115	115	147	77	98	106	81	101	94
	346	347	349	350	350	350	350	350	350	350
197	105	99	102	91	90	116	69	97	97	106
	350	350	350	350	350	350	350	351	351	351
198	87	120	90	118	83	114	111	108	134	87
	351	351	350	350	350	349	341	341	314	311
199	114	108	65	107	106	57	107	115	76	114
	307	304	304	304	303	303	303	303	303	303
200	76	135	87	108	95	144	67	83	135	-
	303	303	303	302	269	268	165	10	5	-

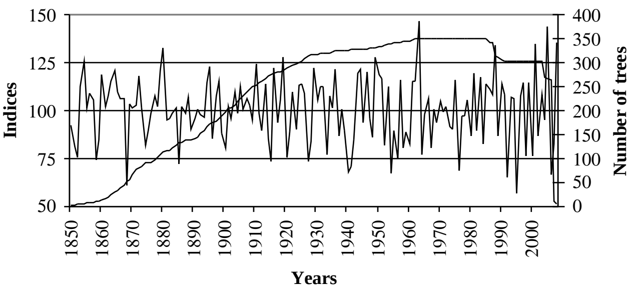

Figure 3. Regional tree-ring chronology of European larch in indices and number of trees for each year

Negative and positive signature years of larch are listed in Table 4; we found 21 negative and 14 positive signature years between 1858 and 2007. The radial growth of 60-90% trees had abruptly decreased during negative signature years, and the growth of 60-89% trees responded positively during the positive signature years.

Table 4. Negative and positive signature years of larch, percentage of trees involved, and climate extremes

Negative signature years			*Positive signature years*		
Year	Number of trees, %	Climate	Year	Number of trees, %	Climate
1858	90	Hot and dry summer	1862	75	No extremes
1868	85	Hot and dry summer	1872	72	Warm spring
1874	66	Cold spring and summer	1880	63	No extremes
1885	74	Hot and dry summer	1895	66	Warm spring
1900	71	Hot and dry summer	1916	62	Warm winter and spring
1915	69	Hot and dry summer	1936	69	Warm winter and spring
1920	67	Hot and dry summer	1944	62	Warm winter
1927	69	Hot and dry summer	1957	68	Warm winter
1933	76	Cold spring and summer	1963	73	Cold winter and spring
1940	74	Hot and dry summer	1975	60	Warm winter and spring
1941	74	Hot and dry summer	1981	60	Warm spring
1954	68	Hot and dry summer	1988	60	Warm spring and summer
1964	71	Hot and dry summer	2001	66	Warm winter and spring
1967	66	Hot and dry summer	2005	89	Warm winter
1976	78	Hot and dry summer			
1984	73	Cold spring and summer			
1992	80	Hot and dry summer			
1995	72	Hot and dry summer			
2000	64	No extremes			
2006	86	Hot and dry summer			
2007	60	Hot and dry summer			

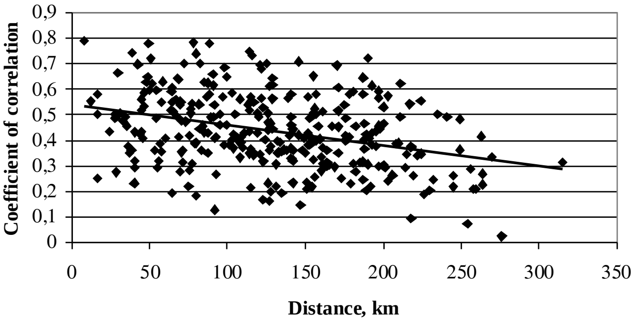

Figure 4. Correlation between the 25 site chronologies of larch

During the negative signature years, dry and hot summers predominated (17 years). Three signature years were presumingly provoked by spring and summer colds, while the causes for the growth reduction in 2000 were unclear.

- Hot and dry summers: 1858, 1868, 1885, 1900, 1915, 1920, 1927, 1940, 1941, 1954, 1964, 1967, 1976, 1992, 1995, 2006, and 2007.
- Cold springs and summers: 1874, 1933, and 1984.

Positive pointer years were provoked by warm conditions in winter and spring (seven and nine years, respectively). The triggers for the growth increase in 1862 and 1880 are not clear.

- Warm winters: 1916, 1936, 1944, 1957, 1975, 2001, and 2005.
- Warm springs: 1872, 1895, 1916, 1936, 1963, 1975, 1981, 1988, and 2001.

The average similarity, expressed as correlation coefficient, between the growth of larch and spruce was +0.39 and statistically reliable on all plots (Table 5), whereas the similarity between the radial growth of larch and pine was on average only +0.17 (statistically reliable on two plots).

Table 5. Coefficients of correlation between the local tree-ring width chronologies of larch, pine, and spruce

Experimental plot	*Norway spruce*	*Significance, p*	*Scots pine*	*Significance, p*
Ąžuolpamūšė	0.38	0.00	0.16	0.13
Gražiškiai	0.51	0.00	-	-
Selema	0.39	0.01	-	-
Suvainiškis	0.26	0.01	0.18	0.05
Sirguškė	-	-	0.17	0.08
Žigla	-	-	0.20	0.03

Discussion and conclusions

Our results demonstrate that the radial growth dynamics of larch is quite homogenous thorough the territory of Lithuania. This is in accordance with the results of the cluster analysis (Figure 2), where the clusters do not reflect a clear geographic structure (Figure 1). The distribution of the site chronologies in the clusters is perhaps related to site differences, such as soil type or ground-water level.

Thirteen of our plots are located in forests and twelve in parks. In consequence, we are lacking an appropriate method for the evaluation of the sites in the experimental plots. For example, a forest type cannot be established in the city parks, and we had no permission for soil and water depth measurements in these parks.

The high mean sensitivity and standard deviation of the site chronologies indicate a high variability of larch tree-ring widths (Figure 3). Oleksyn and Fritts (1991) in Poland have also observed a larger variability (mean sensitivity up to 0.32) of larch tree rings than reported for Alpine sites. The mean sensitivity of Douglas fir in Lithuania was found to be 0.16-0.35 (Vitas and Žeimavičius 2006) and of Norway spruce to be 0.11-0.23 (Vitas 2002). The high mean sensitivity of larch may be attributed to the frequent occurrence of light rings. A light ring refers to a latewood zone with thin-walled cells (Filion and Payette 1986). Light rings were also described for Estonian larch by A. Läänelaid (pers. comm.); he assumes that light rings in larch do not contain a climate signal and likely are caused by the invasions of insects.

European larch is a native tree species in the mountains of central Europe. However, larch in the Alps is less dendrochronologically investigated than other coniferous trees. According to Schweingruber (1985), this can be explained by the questionable suitability of larch for climate reconstructions because of the periodic outbreaks of Gray larch budmoth (*Zeiraphera diniana* Gn.) populations. The response of the trees to these outbreaks interferes with the climatic fingerprint contained in the tree rings (Kress et al. 2009).

Serre (1978) in the French Alps explained narrow rings in larch with a wet and cold previous autumn (September), cold winters, abundant precipitation in summer (June-July), high temperature from March-May, and cool and wet summers. This is in accordance to an investigation by Büntgen et al. (2008), based on a wide network of larch chronologies; they concluded that summer temperatures are positively and strongly correlated with the larch tree-ring widths.

The growth of larch in south-west Poland has a direct link with precipitation in May-June. The temperature in previous June-August has an inverse effect (Oleksyn and Fritts 1991). It indicates a higher water demand of larch than of Scots pine (Polster 1967).

Three studies on tree rings of larch have been carried out in Lithuania. However, they are based on a limited number of sites and trees (Kaminskaitė 2002, Kaselytė 2003, Pukienė and Bitvinskas 2000). Pukienė and Bitvinskas (2000) concluded that the growth of larch is positively connected to cool and humid summers and cold winters. Kaselytė (2003) found an inverse influence of precipitation and air temperature in March and confirmed that larch is less sensitive to winter colds than pine. Kaminskaitė (2002) argued that the growth of larch is positively related to precipitation in summer which partially contradicts Pukienė and Bitvinskas (2000) who recorded a positive interaction between winter colds and tree-ring widths of larch were recorded.

The interpretation of signature years, assessed from the regional tree-ring chronology of larch, was successful. We found that hot and dry summers are responsible for negative signature years. This is in accordance with Oleksyn and Fritts (1991) who found that larch radial growth is directly related to summer precipitation whereas cold springs and summers play only a secondary role. We do not observe a clear negative influence of cold winters to the radial growth of larch. Thus, we confirm Kaselytė (2003) and Pukienė and Bitvinskas (2000), who observed a considerable tolerance of larch to winter colds. The increase in the radial growth was triggered by warm winters and springs. These findings are surprising and are not supported by previous investigations.

Our results show that the growth pattern of larch is quite similar to the growth dynamics of Norway spruce, whereas the similarity with pine is much lower and usually statistically insignificant (Table 5). Therefore, it might be supposed that the radial growth of both species, larch and spruce, is sensitive to similar climatic variables, probably summer droughts.

Our research on European larch is the first one in Lithuania using a wide network of experimental plots. This enabled us to assess the radial growth of larch in different regions of Lithuania. Our preliminary findings based on signature years partially contradict previous investigations, e.g. we found a positive influence of warm winters and springs for the growth of larch which was not observed during previous investigations. It is important to continue this research by investigating climate factors linked to the growth of larch using response function and signature year analyses on the level of local tree-ring chronologies. A collaboration of scientists in the Baltic States is essential to establish the nature of light rings in larch and which environmental information they contain.

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РЕГИОНАЛЬНАЯ ХРОНОЛОГИЯ ГОДИЧНЫХ КОЛЕЦ ЛИСТВЕННИЦЫ ЕВРОПЕЙСКОЙ (*LARIX DECIDUA* MILL.) В ЛИТВЕ

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Резюме

В Литве были проведены дендрохронологические исследования годичных колец лиственницы европейской (*Larix decidua* Mill.), в результате которых была построена региональная хронология. Наши исследования, основанные на 25 экспериментальных площадях (351 дерево), продемонстрировали, что подобный ход радиального прироста характерен для лиственницы, растущей в различных административных регионах Литвы. Радиальный прирост лиственницы характеризуется высокой чувствительностью (в среднем 0.35±0.01) и повторением светлых колец. Построенная региональная хронология охватывает период с 1850 до 2008. Анализ сигнатурных лет показал, что формирование узких колец связано с жаркими/сухими летними временами года, а широкие кольца вызваны теплыми зимами и веснами. Ход радиального роста лиственницы был подобен таковому ели обыкновенной, произрастающей в смешанных древостоях (корреляция от 0.26 до 0.51, p?0.01), в то время как сходство с сосной обыкновенной было намного меньше (корреляция от 0.16 до 0.20, а p от 0.03 до 0.13).

Ключевые слова: лиственница европейская, Литва, региональная хронология годичных колец, ширина годичных колец, сигнатурные лета, климат