Chapter 14
Growth/Climate Relationships in Tree-Ring Widths of *Picea Abies* in Lithuania and Poland

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14.1 Introduction

14.1.1 Aim of Study

Tree-ring-widths together with parameters including wood density, stable isotope content and the presence of reaction wood (anomalous, high-density cells produced as a result of mechanical stress, termed 'compression wood' in conifers) are frequently used as bio-indicators to study environmental conditions (Schweingruber 1996). Some factors such as frost or summer drought, may have an immediate effect on ring width, other factors such as wintertime drought may have a delayed effect on tree-ring-widths, since the growing tissue is dormant. The effect of different factors is seen as variation in ring size and structure, which changes systematically, or vary slowly throughout the life of the tree (Fritts 1976).

Spruce is a popular tree species in European forestry, and in dendrochronological and dendroclimatological research. Previous dendrochronological studies on spruce in Poland have generally focussed on trees from the mountainous region (Bednarz et al. 1998–1999; Feliksik and Wilczyński 2000a, 2000b, 2001; Savva et al. 2006). Lowland spruces in Poland and Lithuania have been studied mainly by authors of this paper: Zielski and Koprowski (2001, 2002); Koprowski and Zielski (2002, 2006, 2007); Vitas (2002, 2004). Because of the

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transition zone between Atlantic and continental climates, we decided to generalise the climate-growth response of spruce on the selected sites in natural stands in Poland and Lithuania as a basis for climate reconstruction. Dendrochronological regionalisation allows usage of a limited area for each reconstruction.

14.1.2 Climate of Study Area

Climatic conditions and biogeographical differences are expressed as influence of oceanic and continental climates. The Polish lowland (60%) belongs to the Middle-European Lowland, and has generally sub-Atlantic vegetation, and a predominantly oceanic climate. The mean yearly precipitation – 450–700 mm, and the mean yearly temperature – 7–9°C. Southern Poland is characterised by uplands and mountains. Northeastern Poland and Lithuania were connected to the Lowland East-Baltic-Belorus. The dominance of the Atlantic climate decreases from the south to the northeast of the research area (Kondracki 2002). Average yearly temperature in Lithuania is +6.1°C (−4.9°C in January and +17.0°C in July). The western region of Lithuania is characterized by highest amounts of precipitation per year (up to 930 mm), warmest winters (January temperature of −2.8°C) and the longest period of vegetation (200–206 days). The smallest amount of precipitation (520–620 mm per year) is characteristic of North Lithuania. Warmer winters and summers than those in the North and East are indicative of South Lithuania. The most continental climate conditions with the shortest period of vegetation (185–192 days) and coldest winters (−5.0°C to −6.8°C) are characteristic of East Lithuania (Bukantis 1994).

14.2 Material and Methods

14.2.1 Tree Sites and Sampling Method

Almost 2,000 samples were taken from 45 sites from different habitats in eastern Poland and from 47 sites in Lithuania[1] (Fig. 14.1). Between ten and 30 dominant trees, without visible disease symptoms, were selected from each site. Two core samples were taken from each tree, one from the west and one from the east, using a Pressler borer, at a height of approximately 1.30 m above ground level. Samples from Polish Uplands were taken with mean elevation of approximately 200–300 m a.s.l.

[1] Site descriptions available upon request

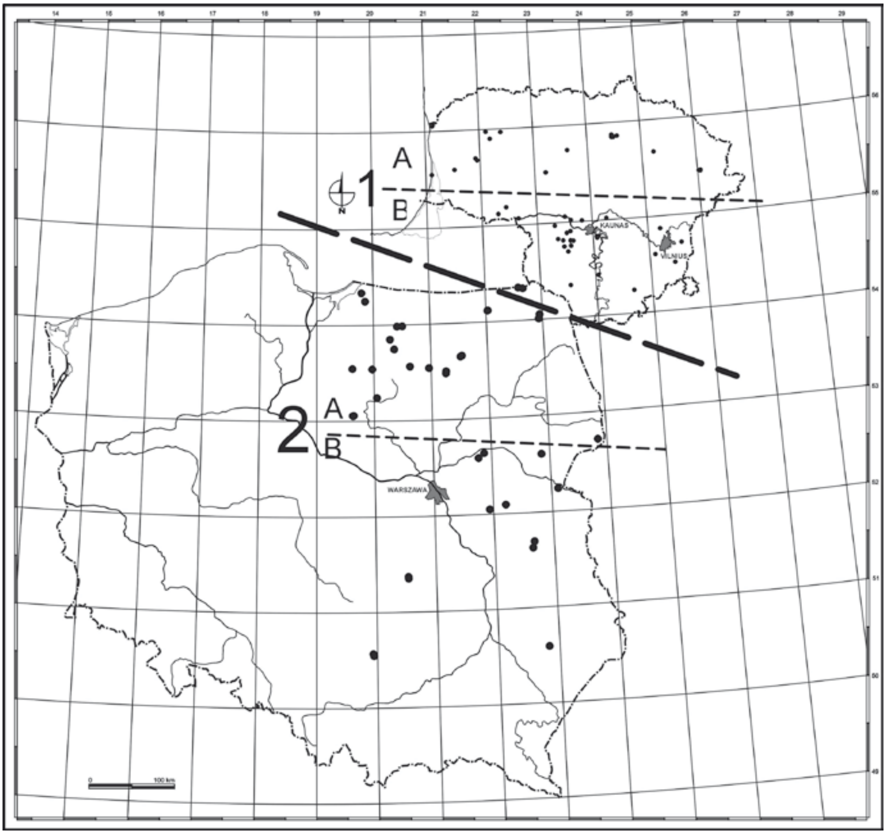

Fig. 14.1 Sites location, established homogenous regions

14.2.2 Local Chronologies

The core samples were treated in the standard way and measured to the nearest 0.01 mm by means of a mechanical instrument with a computer registering the ring widths. The samples from each site were then used to construct local chronologies. A number of methods were used to assess the cross-matching between the samples:

- The Students-*t* test. Only the samples whose *t*-value was greater than 4.0 were used to build a chronology.
- Gleichläufigkeit. The CATRAS program (Aniol 1983) was used to compute the % Gleichläufigkeit (% GL). This is a non-parametric measure of the congruity of two growth curves, which consists of comparing subsequent intervals (Eckstein 1969; Schweingruber 1983).
- The accuracy of the fit was tested by the COFECHA program (Holmes 1986; Grissino-Mayer 2001).

– Each sample was analysed by means of skeleton plot method (Douglass 1939; Schweingruber et al. 1990). To check the measuring mistakes, pointer years were detected and applied.

The following two types of chronologies were used for further investigations:

– Raw data chronology – composed of averaged annual growth values and presented in the form of actual numerical values.
– Residual chronology, which was built by CRONOL, a tool from the DPL package (Holmes 1984).

14.2.3 Regionalisation

Hierarchical cluster analysis (HCA) was used to distinguish regions with similar increment patterns. This method has been successfully employed by Leuschner and Riemer (1989) and Wilson and Hopfmüller (2001) to distinguish groups of trees at varying altitudes. The STATISTICA program was used to perform the HCA. To maximise the between-group variance, while minimising the within-group variance, Ward's method was used, with Pearson's correlation coefficient being used as a measure of the similarity.

14.2.4 Dendroclimatological Analysis

Climate-growth relationships were calculated by means of the PRECON program (Fritts 1996). This program applies a bootstrap response function to estimate the error using random sampling from the data. The response function method has been described in detail by Fritts (1976), and Briffa and Cook (1990). The bootstrapped procedure provides an alternative to testing the significance and stability of the regression coefficient (r) in time. It is based on the evaluation of a large quantity of data (subsamples). It has been found that with more than 50 sub-samples, the results do not vary considerably. The regression coefficient is calculated for each randomly selected sub-sample. If this is repeated 50 times, we get 50 regression coefficients, and 50 independent verifications of the correlation. At the final stage, the results of these parameters are calculated on the basis of the preceding 50 measurements (Guiot 1993). Climate data from October of the previous year to September of the current year served as independent variables, and the residual chronologies for each site were used as dependent variables. In all bootstrap calculations, 50 bootstrap replications were calculated.

Mean monthly temperatures and monthly precipitation sums were collected from 16 meteorological stations of the Institute of Meteorology and Water Management in Warsaw and four meteorological stations from Lithuania.

14.3 Results and Discussion

14.3.1 Dendroclimatological Regionalisation

Regionalisation was made by comparison of 79 local chronologies, distinct regions with a similar increment pattern were identified by HCA. Some chronologies were rejected because of young age of trees. We were able to recognize four main groups, where linkage distance is higher than two (Fig. 14.2). Group 1 is composed of Lithuanian sites and two sites from north-eastern Poland. Group 2 consists of sites only from Poland. The first group is divided into two smaller groups “1a” and “1b”. Trees from the region “1a” grow in northern Lithuania and from the group “1b” in the southern part of the country and in Poland (Figs. 14.1 and 14.2). These chronologies split from the same branch in the hierarchical tree, and indicate that the yearly variance of tree-ring widths share some of the variation with the trees from other sites. The border between region “1a” and “1b” is approximately the same as between northern and southern climate regions of Lithuania, but this line divides the eastern area into north and south. Two sub-groups from region 2 represent trees from north-eastern Poland on the one hand and from middle and southern Poland on the other. The border between these groups (2a and 2b) confirms the idea that spruce from the Hercynian-Carpathian centre reached the middle Wisła and Bug River, and the southern border of boreal-Baltic range is the border between two ranges. The problem of spruce range and dendrochronological regions was discussed in detail by Koprowski and Zielski (2006). Savva et al. (2006) grouped *Picea abies* chronologies at different elevations, and they observed that shifting elevational pattern may be associated with the length of the growing season. The shortest vegetation period is characteristic of East Lithuania (185–192 days) and Suwalskie Lakeland (185–190 days). This gives an approximate difference of 3 weeks in comparison with west and south-east Poland. In western Lithuania, the vegetation period lasts 200–206 days. The border between regions 1a and 1b is rather more connected with rainfall. The northern part of Lithuania has the smallest amount of precipitation, especially in comparison to the western part – up to 930 mm. In Poland, the dominance of the Atlantic climate decreases from the south to the northeast, while the effects of the continental climate increase. This is expressed as a higher mean yearly precipitation, a decrease in the vegetation growth period, and a greater yearly temperature amplitude. Regionalisation accomplished for other species e.g. pine in Poland (Wilczyński et al. 2001) gave similar results as for spruce. This suggests that supra-regional factors like climate play an important role in determining tree-ring growth, in some way independently from local environmental conditions and tree species.

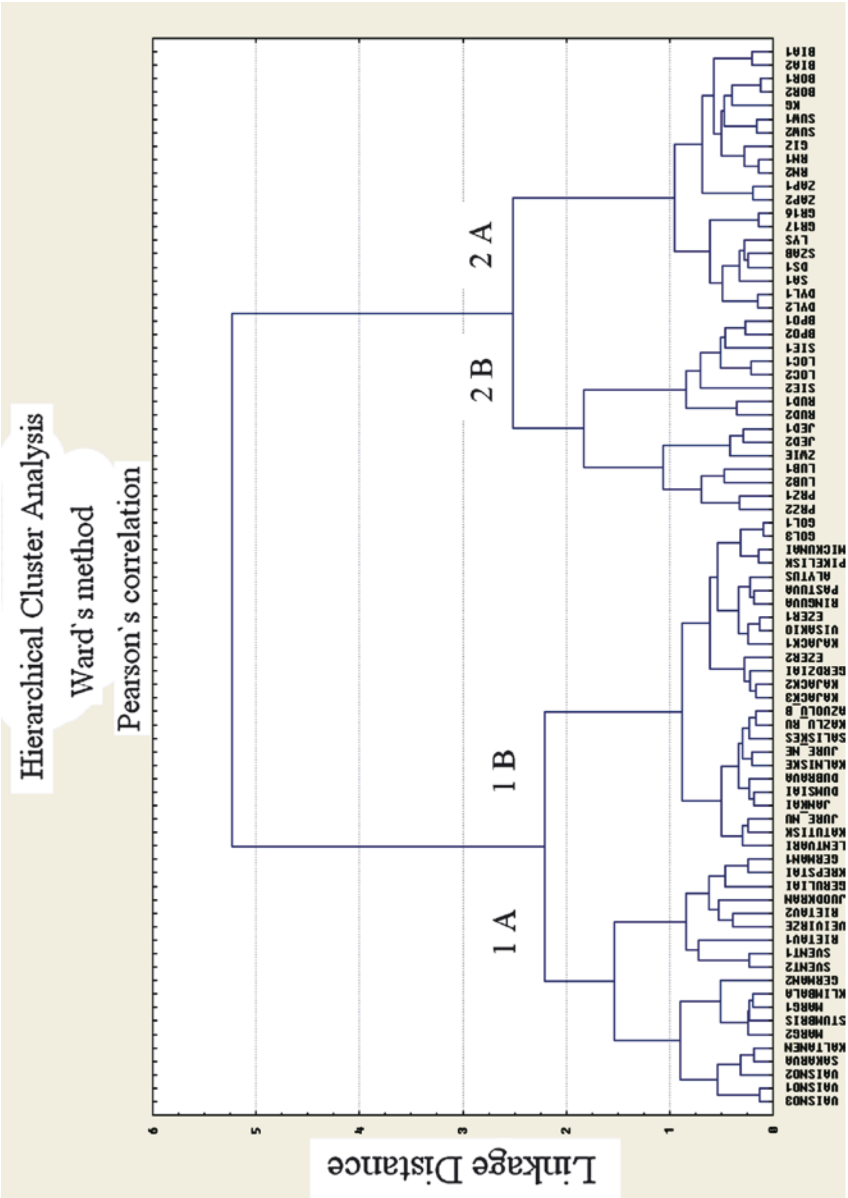

Fig. 14.2 Results dendrogram of cluster analysis

14.3.2 Growth/Climate Relationships

In the second part of our paper, we would like to focus on climatic conditions, which determined tree growth and may be a key factor understanding the spatial distribution of increment patterns. Results of the dendroclimatological research are presented in Tables 14.1, 14.2, 14.3 and 14.4. Trees from the region "1a" respond mostly to precipitation during the vegetation period, especially from June to July (Table 14.1) and the variance explained by climate varies from 46% to 2%. Trees from most sites respond to precipitation, whilst only three sites are sensitive to temperature. Regions 1b and 2a seem to be temporal instable. The reaction to climate is mixed; some trees react more to precipitation, some to temperature (Tables 14.2 and 14.3). Wilson and Elling (2004) took into account the problem of temporal instability in growth-climate response and demonstrated some implications for dendroclimatic reconstructions. They concluded that, due to SO_2 forcing in southern Germany, the calibration period for spruce ring-width will be restricted to the 1871–1978 period. Spruces from lowlands (regions 1b and 2a) are most flexible on weather conditions in the vegetation period. In the region 1b (most Lithuanian sites) the role of precipitation also lasts for 2 months from May to June, while in north-eastern Poland this extends to July. Trees from a few sites respond negatively to high summer temperatures. A quite different correlation was stated by Bednarz et al. (1998–1999) for Babia Góra National Park (Carpathian Mts.). Here, high June–July precipitation had a negative effect on tree growth, on the contrary to summer temperature, which is strongly positively correlated with tree-ring-widths. This is due to high annual precipitation meaning and therefore moisture is not a limiting factor, and summer droughts are extremely rare. Negative correlation to summer precipitation in cooler regions was found too by Mäkinen et al. (2000, 2003) or Miina (2000). Trees from warmer regions of eastern Finland (Mäkinen et al. 2003), or in the lower altitude mountains in Germany (Dittmar and Elling 1999; Wilson and Hopfmüller 2001) and the northern part of this country (Eckstein et al. 1989) react in the same way. The role of precipitation and temperature during the vegetation period was also described by Kahle and Spiecker (1996), Mäkinen et al. (2001), Meyer and Bräker (2001), Dittmar and Elling (2004).

On some sites, the influence of different climate conditions from other months was noted. The warm November temperatures had a negative influence at two sites in the Forest Inspectorate areas of Lidzbark (Grodki 17), Goldap and site Mickunai. The reason for that could have been the disruption to the tree passing into its winter phase if trees are not tough enough that is a gradual temperature decline in winter months prepares plants to withstand frost (Obmiński 1977). In certain Polish spruce sites, high temperatures in January and February produce a positive influence meaning the subsequent formation of wide rings is observed. During earlier investigations carried out in the Olsztyn Lake District (though on a shorter sequence of climatic data), one of the sites showed a negative impact of high February temperatures (Zielski and Koprowski 2002). This may be a result of snow loading on the branches. This phenomenon is strengthened when wet snow falls at the temperature

Table 14.1 Region 1a. Relationships between residual chronology and monthly values of temperature and precipitation in previous year (O-October, N-November, D-December) and current year (J-January, F-February, M-March, A-April, M-May, J-June, J-July, A-August, S-September), p-positive dependence, n-negative dependence. RSQ-R^2, CL- variance explained by climate, P GRO- variance explained by prior growth, TOT- total explained variance

Site	Temperature												Precipitation											RSQ:		
	Previous year			Current year									Previous year			Current year								CL:	P GRO:	TOT:
	Months												Months													
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	F	M	A	M	J	J	A	S			
German 1																				**p**	**p**			0.39	0.01	0.4
German 2									**n**															0.45	–0.04	0.41
Geruliai						**p**														**p**				0.41	–0.04	0.37
Juodkran																				**p**	**p**			0.46	0.08	0.54
Kaltanen																				**p**				0.35	–0.18	0.17
Klimabala																								0.12	–0.01	0.11
Krepsiai	**p**					**p**															**p**			0.24	–0.03	0.21
Merg 1																								0.19	0.00	0.19
Merg 2																				**p**				0.23	0.12	0.35
Rietav 1																								0.08	0.07	0.15
Rietav 2																				**p**				0.28	0.06	0.34
Sakarva																				**p**				0.11	–0.23	–0.12
Stumbris																								0.07	0.1	0.17
Svent 1																								0.02	–0.25	–0.23
Svent 2																								0.02	–0.09	–0.07
Vaisno 1																				**p**				0.26	–0.07	0.19
Vaisno 2																				**p**				0.36	–0.15	0.21
Vaisno 3																				**p**	**p**			0.28	–0.02	0.26
Veivirze																								0.02	–0.05	–0.03

Table 14.2 Region 1b. Symbol and shortcuts as above

Site	Temperature												Precipitation												RSQ:		
	Previous year					Current year							Previous year					Current year							CL:	P GRO:	TOT:
	Months												Months														
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	F	M	A	M	J	J	A	S				
Alytus																				**p**					0.07	0.06	0.13
Ąžuolų Būda																									0.08	0.19	0.27
Dubrava 2															**p**										0.17	0.13	0.3
Dumsiai			**p**																						0.14	0.07	0.21
Ežerélis 1																				**p**					0.39	0.11	0.5
Ežerélis 2																									0.33	0.2	0.53
Gerdžiai		**n**				**p**			**n**		**n**														0.33	0.21	0.54
Goll						**p**														**p**					0.47	0.13	0.6
Gol3																				**p**	**p**				0.52	0.081	0.6
Jankai									**n**				**p**						**p**						0.26	0.12	0.38
Jūré Ne													**p**												0.11	0.04	0.15
Jūré Nu																									0.07	0.14	0.21
Kajackai K						**p**														**p**	**p**				0.37	0.08	0.45
Kajackai P						**p**																			0.25	0.08	0.33
Kajackai S						**p**													**p**						0.37	0.02	0.39
Kalniské																									0.14	0.01	0.15
Katutiskés																**p**									0.21	0.07	0.28
Kazlų Rūda																									0.09	0.11	0.2
Lentvaris		**n**													**p**										0.39	0.1	0.49
Mickūnai																									0.37	0.17	0.54
Paštuva																				**p**					0.23	0.12	0.35
Pikeliškés															**p**										0.23	0.11	0.34
Ringuva											**n**									**p**					0.43	0.17	0.6
Šališkés																			**p**						0.13	0.00	0.13
Višakio Rūda											**n**								**p**						0.26	0.17	0.43

Table 14.3 Region 2a. Symbol and shortcuts as above

Site	Temperature												Precipitation											RSQ:		
	Previous year				Current year								Previous year				Current year							CL:	P GRO:	TOT:
	Months												Months													
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	F	M	A	M	J	J	A	S			
Suwalki 1																			**p**	**p**	**p**			0.54	0.15	0.69
Suwalki 2																			**p**	**p**	**p**			0.532	0.092	0.624
BPN																			**p**	**p**	**p**			0.457	0.147	0.604
Borki 1									**n**															0.462	0.154	0.617
Borki 2																			**p**	**p**				0.427	0.182	0.609
Sarny 1																			**p**	**p**				0.491	0.106	0.597
Gizewo					**p**														**p**		**p**			0.436	0.133	0.57
Ruciane Nida 1																			**p**	**p**		**p**		0.48	0.126	0.606
Ruciane Nida 2																				**p**				0.437	0.129	0.566
Dwa Stawy 1									**n**										**p**	**p**				0.476	0.144	0.621
Kamienna G																								0.401	0.17	0.571
Szabruk																			**p**		**p**			0.575	0.081	0.655
Grodki 16									**n**										**p**	**p**				0.448	0.093	0.541
Grodki 17		**n**							**n**										**p**		**p**			0.505	0.115	0.666
Zaporowo 1						**p**									**n**						**p**			0.456	0.155	0.611
Zaporowo 2						**p**									**n**									0.44	0.101	0.541
Dylewo 1																			**p**	**p**	**p**			0.491	0.093	0.584
Dylewo 2	**p**								**p**									**p**	**p**	**p**	**p**			0.595	0.115	0.71
Lysowo						**p**												**p**		**p**				0.545	0.123	0.667

Table 14.4 Region 2b. Symbol and shortcuts as above

Site	Temperature												Precipitation											RSQ:		
	Previous year				Current year								Previous year			Current year								CL:	P GRO:	TOT:
	Months												Months													
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	F	M	A	M	J	J	A	S			
Rudka 1							**n**												**p**	**p**	**p**			0.543	0.199	0.742
Rudka 2						**p**	**n**												**p**					0.434	0.18	0.613
Biala Pdl. 1						**p**			**n**															0.406	0.091	0.498
Biala Pdl. 2				**p**		**p**																		0.417	0.122	0.539
Lochow 1				**p**					**n**											**p**				0.537	0.118	0.655
Lochow 2						**p**			**n**															0.411	0.078	0.489
Siedlce 1						**p**		**n**																0.395	0.122	0.516
Siedlce 2																				**p**	**p**			0.531	0.00	0.531
Przysucha 1						**p**																	**n**	0.401	0.09	0.491
Przysucha 2						**p**																		0.412	0.073	0.485
Jedrzejow 1						**p**																		0.436	0.197	0.634
Jedrzejow 2						**p**																		0.315	0.309	0.624
Lubartow 1																								0.33	0.157	0.487
Lubartow 2																							**n**	0.401	0.151	0.552
Zwierzyniec																								0.38	0.137	0.517

of 0°C (Modrzyński 1998). Skre and Nes (1996) found that high winter temperatures may cause an increased needle loss and lead to growth reduction in the following season. A negative correlation between February temperature and subsequent ring width was observed in Finland (Miina 2000; Mäkinen et al. 2000).

Spruce from southern sites grows under the influence of the highland climate, with a stronger role of March temperature. In the Ustron Forest District of the Polish mountains, the low temperatures of the end of winter and during spring were a limiting factor. The higher the altitude of the site, the longer the period of time during which higher temperatures positively influenced cambial activity (Feliksik and Wilczyński 2000b).

14.4 Conclusions

Dendroclimatological research on Norway spruce in Poland and Lithuania gives an opportunity to extend the knowledge of spruce ecology and to follow the climate growth relationships in regard to climate reconstruction. Regionalisation based on growth increment patterns divided the research area into four regions, the most northern sites (Lithuania and north-eastern Poland) are more sensitive to rainfall during the vegetation period. In northern Lithuania precipitation from June to July is the most important for tree growth, while in southern Lithuania this period is from May to June. In north eastern Poland the influence of precipitation from May to July prevails. We concluded that tree-ring-widths from these three regions (1a, 1b, 2a) are mostly determined by precipitation during the vegetation period, especially from May to July. Differences in growth patterns are not so clearly related to the length of vegetation period, which varies from 185–192 days in East Lithuania and 185–190 days in Suwalskie Lakeland to 200–206 days in western Lithuania. The border between the length of a vegetation period in Lithuania extends from north to south while the border of selected dendrochronological homogenous regions runs from the West to the East. This difference is rather connected with rainfall; the smallest amount of precipitation is noted in northern Lithuania whilst in Poland the effects of continental climate increase from the south to the northeast. This is expressed, among other parameters, as higher yearly mean precipitation. The decrease in dominance of the Atlantic climate from the south to the northeast is also responsible for distinguishing regions 2a and 2b. This is visible in their reaction to climate. Trees from the southern part of Poland (region 2b) are more sensitive to March temperature. We concluded that, with regard to climate reconstruction, it is possible to reconstruct precipitation from May to July for north-eastern Poland and Lithuania.

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