

Radial growth variation between four provenances of Norway spruce in the conditions of central Poland

Marcin Klisz^{1*}, Szymon Jastrzębowski¹, Longina Chojnacka-Oźga², Jan Kowalczyk¹

¹ Forest Research Institute, Department of Silviculture and Genetics, ul. Braci Leśnej 3, Sękocin Stary, 05–090 Raszyn, Poland;

² SGGW – Warsaw University of Life Sciences, Department of Forest Silviculture, Faculty of Forestry, ul. Nowoursynowska 159, 02–776 Warszawa, Poland.

*Tel. +48 22 715 03 52, e-mail: M.Klisz@ibles.waw.pl

Abstract. The purpose of this study was to determine the growth variability of four provenances of *Picea abies* on experimental plots in the Wyszków Forest District, central Poland. The experiment was established as a system of random blocks with four repetitions per block. We selected 48 trees from each provenance and the increment cores were collected from sample trees. Standard measurements of the width of annual increments were performed using the WinDendro software. Raw data was then indexed and subject to dendroclimatic analyses based on the average monthly temperatures and precipitation of the period from 1969 to 2012. Furthermore, the COFECHA software was used to check the consistency of the data and to determine the pointer years. High data consistency as well as growth variability of particular provenances in response to climatic conditions was observed. The results obtained here will allow for an improved selection of populations best suited for growing in the climate of central Poland.

Keywords: dendrochronology, climate, pointer years, spruceless area

1. Introduction

Spruce is one of the main forest-forming species in Poland. According to Śródoń (1976), this species occurs in two distinct areas in Poland. Central and northwestern Poland lacks natural sites of this species, although it has been artificially introduced there. This is called the ‘spruceless’ area. The origin of the spruceless area has been the subject of many years of ongoing discussion, resulting in several theories:

- It is a natural border separating areas of lowland and mountain spruce.
- It is the southern limit of the range of spruce from the northwest, designating the species’ unfinished migration to the south (Szafer 1931, Schmidt-Vogt 1977).
- It was created as the result of deliberate forest management in areas unfavourable for the growth of spruce (Hensel 1980, Broda 1998).

The last theory is supported by recent studies on the effects of climate on the radial growth of spruce in different provenances (Koprowski and Zielski 2006; Koprowski 2013).

One of the aims of numerous provenance studies on the adaptive possibilities of spruce, originating from its natural range as well as outside of it, was to find a population able to grow in the habitat of the spruceless area (Giertych 1972, 2000; Krupski and Giertych 1996). However, mainly growth and qualitative characteristics were analysed. To date, few studies on the provenance of spruce were devoted to the relation between genetic determinants of radial growth and climate (Burczyk and Giertych 1988, 1991; Koprowski 2008). Based on the results of similar studies on other conifer species, it can be assumed that such diversity exists (Oleksyn and Fritts 1991; Savva et al. 2002; Eilmann et al. 2013; Bijak, 2013). Spiecker (2002) indicates a genetic basis for growth variation in response to climatic conditions.

Received: 23.07.2014, reviewed: 18.08.2014, accepted: 29.08.2014.

According to Koprowski (2013), projected climate changes will most likely equally affect the growth of spruce populations from its natural range, as well as from the spruceless area. The most recent dendroclimatic studies indicate that the reaction is on a supra-species (affecting all coniferous species) (Bijak 2013) or supra-regional level (Koprowski and Vitas 2010).

The aim of this study is to verify the hypothesis of the existence of differences in dendroclimatic reactions among northern Norway spruce provenances growing in an experimental plot located in central Poland.

2. Materials and method

The study material consisted of trees from the Norway spruce provenance area of the Wyszków Forest District, Dalekie Forest Range, division 99i (52°41'24"N 21°33'58"E), founded in 1963. Four of eleven spruce provenances from northern Poland were chosen; two characterised by the best productivity – Kartuzy (provenance 11) and Mestwinowo (provenance 8), and two by the worst productivity – Augustów (provenance 4) and Górowo Iławieckie (provenance 7) (Matras et al. 2006; Kowalczyk, unpublished data). These provenances also represent populations within the natural

range of spruce – Augustów and Górowo, as well as in the spruceless area – Kartuzy and Mestwinowo (Fig. 1).

Pith to bark increment cores at 1.3 m height were taken from 192 trees, 48 from each selected provenance. The core samples were prepared according to standard techniques and then the width of annual rings was measured and individual sequences were established for each tree with WinDENDRO. Tree-ring sequences were verified: the accuracy of the dating and the homogeneity of the series were confirmed using the COFECHA program with the DPL package (Holmes 1999; Grissino-Mayer 2001). Series with the lowest linear correlation coefficients and series incompatible with others were discarded from further analysis (a total of 10 series were rejected). Then, the chronologies of each provenance were established – the actual and residual – with the Arstan DPL program package (Cook 1985; Cook et al. 1990). A 64-year filter was applied in the standardisation process. The similarity between chronologies was analysed using convergence coefficient GL, t-value and correlation coefficient ($\alpha = 0.05$). The amalgamation method of cluster analysis (Tryon 1939) was used to compare the growth patterns of the analysed Norway spruce provenances. In constructing hierarchical graphs, the Euclidean distance was adopted to calculate the proximity of the groups. The distances between clusters were determined

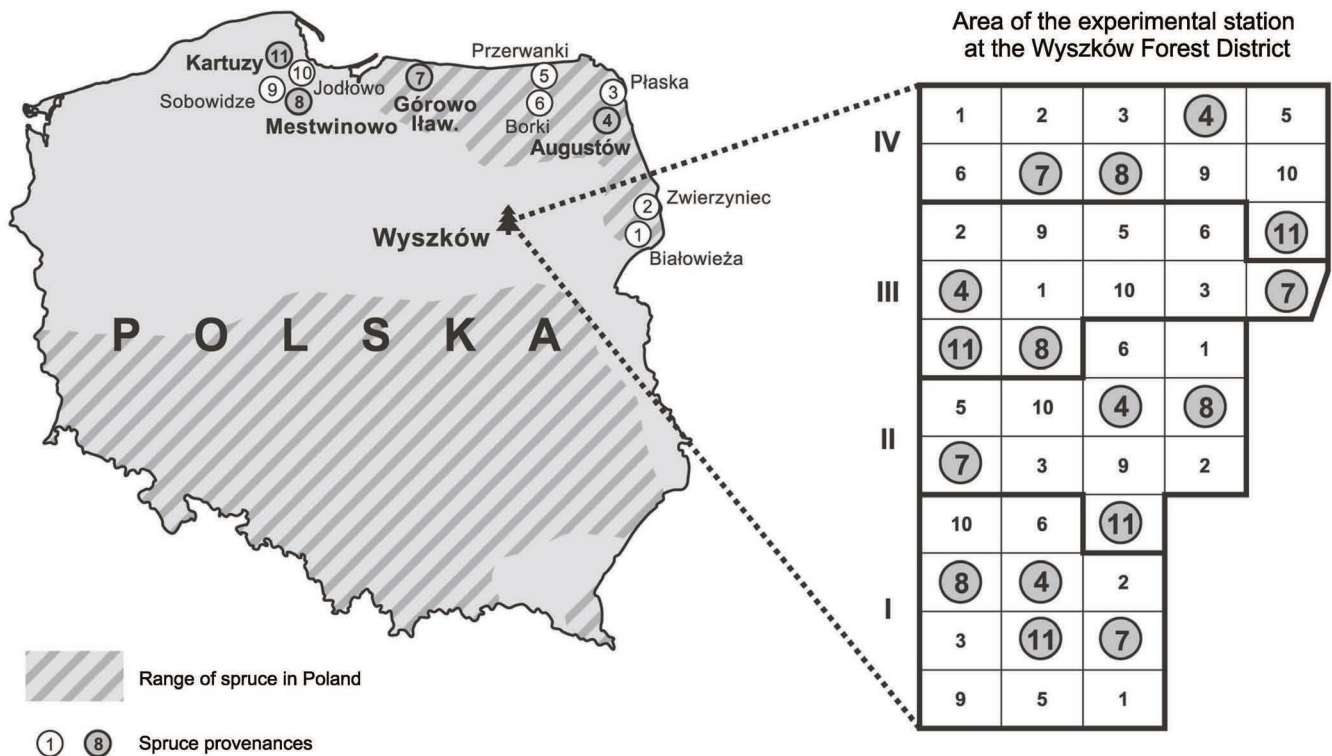


Figure 1. Location of the analysed provenances and diagram of the experimental plot

by the complete linkage method, in which the distance between clusters is determined by the greatest of the distances between any two objects belonging to different clusters. Climate–tree growth relationships were examined for the period of 1980–2012 using a mathematical model of the response function (RESPO program) (Briffa and Cook 1990). Residual chronology parameters of the specific provenances were used as growth parameters. Climatic parameters (mean monthly air temperature and monthly precipitation totals) were obtained from the Meteorological and Hydrological Institute station in Warsaw. The range of climate variables included 17 months of data, from May of the year preceding the formation of tree rings to September, when the ring had completed its growth. Pointer years were determined using the WEISER program

(Gonzalez 2001) for each provenance, as well as for all of them together. A compliance threshold of 80% with a minimum number of 10 trees per provenance was adopted.

3. Results

The analyses exhibited a high degree of agreement for all growth curves, both for individual sequences representing specific provenances, as well as for the chronology of the provenances. The degree of similarity of the chronology constructed for each provenance was high (Figs 2 and 3; Tables 1 and 2). The multiple range test used to compare the analysed provenances did not confirm significant differences among the provenances.

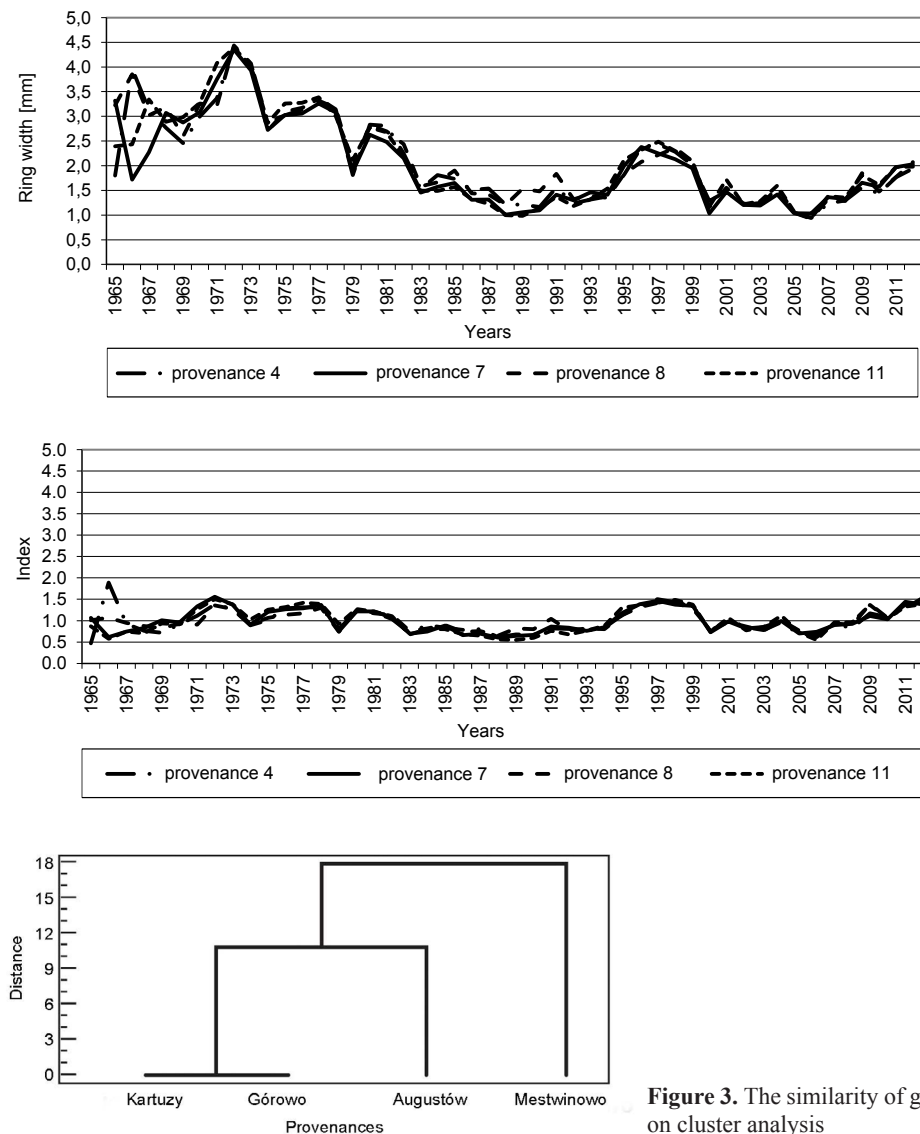


Figure 2. Actual (upper graph) and residual (bottom graph) chronologies of the analysed spruce provenances. Forest districts: Kartuzy (provenance 11), Mestwinowo (provenance 8), Augustów (provenance 4) and Górowo Iławieckie (provenance 7)

Figure 3. The similarity of growth patterns for spruce provenances based on cluster analysis

Table 1. Characteristics of the chronologies representing each provenance

Provenance	No. of trees	Chronology					
		type	average	standard deviation	coefficient of variation	average sensitivity	autocorrelation
Augustów	49	raw data chronology	2.1	0.8353	40%	0.1718	0.8009
		residual	1	0.2226	22%	0.2425	0.0094
Górowo	48	raw data chronology	2.01	0.8337	41%	0.1701	0.8486
		residual	1	0.2437	24%	0.2626	0.1127
Mestwinowo	48	raw data chronology	2.15	0.8594	40%	0.1836	0.815
		residual	1	0.2104	21%	0.2531	-0.025
Kartuzy	47	raw data chronology	2.12	0.8651	41%	0.1578	0.8935
		residual	1	0.2788	28%	0.2926	0.09

Table 2. The degree of similarity of the chronologies representing each provenance

×	GL Coefficient [%]			
	Augustów	Górowo	Mestwinowo	Kartuzy
Augustów	X	79	79	85
Górowo	15.80	X	85	81
Mestwinowo	17.34	17.26	X	79
Kartuzy	20.01	14.82	17.20	X

The growth reaction of trees from various provenances to climatic conditions was similar. The analysis of the response function indicated that the relation between growth and climate is similar for each series representing a particular provenance. Thermal conditions affect radial growth mainly in the period preceding the formation of the ring – May, June, September and November of the previous year (Fig. 4). Precipitation conditions of the growing season, both in the year preceding ring formation as well as in the year of growth, affect its size (Fig. 5). The dependencies presented of radial growth to thermal and precipitation conditions were the same for each of the four provenance studies.

Ten pointer years were designated: five positive ones, that is, those in which growth increment was especially high (1995, 2001, 2004, 2007, 2009), and five negative years, in which growth was small (1979, 1983, 1986, 2000, 2005). These were common to all provenances. Negative years were characterised by low rainfall during the growing season. Climatic conditions in positive years did not differ from the long-term data published by the Central Statistical Office (Domańska et al. 2009).

4. Discussion

A comparison of the growth patterns of the four Norway spruce provenances showed no statistically significant differences regardless of the test used (t-value, sign test-G). These results are consistent with those obtained by Burczyk and Giertych (1988) and Koprowski (2008). Burczyk and Giertych (1991) found that the lack of differences between the provenances was due to the methodology of choosing sample trees, which gave preference to trees of similar dbh values. Note, however, that the present study selected trees from the I, II and III Kraft biosocial classes. Burczyk and Giertych (1991) also indicate a significant influence of microhabitat conditions on different dendroclimatic reactions among provenances and on the lack of an influence of microhabitat conditions on the relationship between radial increment and climate. Researchers are divided on the issue of whether a reaction in radial growth to extreme climatic conditions is genetically determined. Although Burczyk and Giertych (1991) found no such relationship for the Norway

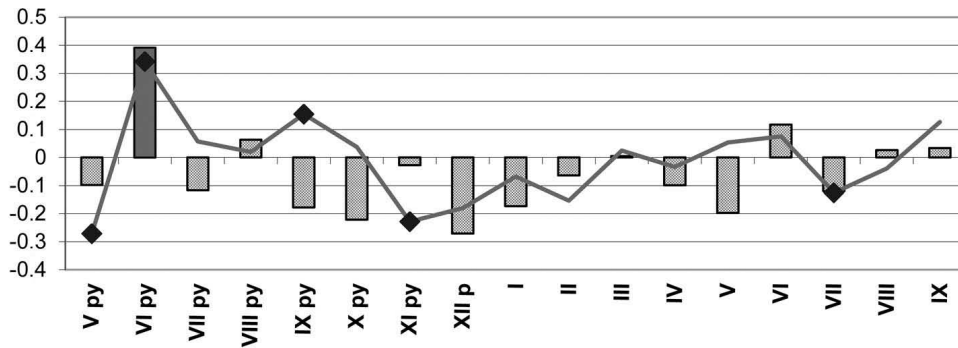


Figure 4. Coefficients of correlation (bars) and regression (points) of average growth values of spruce provenances and air temperature; statistically significant values ($\alpha = 0.05$) are indicated with black bullets and dark grey bars. py – preceding year

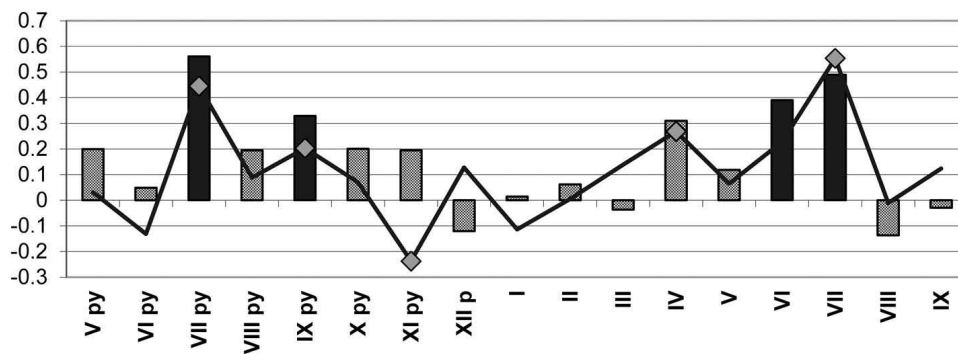


Figure 5. Coefficients of correlation (bars) and regression (points) of average growth values of spruce provenances and precipitation; statistically significant values ($\alpha = 0.05$) are indicated by grey bullets and black bars. py – preceding year

spruce, Elmann et al. (2013) did in their investigation of Douglas fir provenances, which depended on the origin of the stock. In their research, provenance trees characterised by wide annual increments clearly responded to drought. Thus the cited authors associated a higher resistance to drought stress with low productivity of a population, and therefore narrower increments. Savva et al. (2002) reached interesting conclusions in research on Russian Scots pine provenances. They found that as the distance of the place of origin of a provenance increased from the experimental plot, the impact of local weather conditions decreased. In our study, the distance of specific provenances from the test site was similar. For this reason, we anticipated a similar effect of climatic conditions on the radial increment of all four populations.

The analysis of the similarities of growth patterns among the provenances showed a clear difference between the population from Mestwinowo and the others. However, it should be recalled that there were no significant differences between the growth patterns of the studied provenances. The research of Giertych (2000) allows us to explain this phenomenon by

the forest management and planting conducted by the Prussian state in this region at the beginning of the 20th century. Populations that are now in Poland were managed in a similar manner at that time, regardless of whether they were located in the natural range of spruce occurrence or in the spruceless area. Thus there is no reason to believe that the direction of introduction differed for various populations. This may also explain the lack of significant differences in growth patterns in this study. Koprowski (2013) found that regardless of whether spruce populations were from the natural range or not, the increment response to climatic conditions was the same.

The results of the relationship of radial increment to climatic factors were similar for each analysed provenance. Previous studies found no correlation between the radial increment of spruce and mean temperature in June of the year preceding the analysed growing season. The negative correlation of this characteristic with the temperature in July, September and November of the preceding year, while not statistically significant, was confirmed in the research of other authors (Zielski and Koprowski 2001; Bijak 2009;

Rybniček et al. 2012a, b). The nonspecific radial growth response of spruce to the mean temperature in June may be related to climatic conditions, which, according to Koprowski and Zielski (2003), affect the growth pattern of this species and determine its spatial distribution.

The analysis of correlation between the radial increment of spruce and precipitation confirmed a positive and significant relationship with the rainfall in July and September of the preceding year, as well as in June and July of the growth year. These results correspond with those of areas with similar geographical conditions (Zielski and Koprowski 2001; Koprowski and Zielski 2006; Bijak 2009) as well as from sites located both south (Rybniček et al. 2012a, b) and north (Vitas 2004) of the study area. The similar nature of radial growth response to climate in different locations casts doubt on the hypothesis of the varying influence of environmental factors on radial growth in different regions (Mäkinen et al. 2003).

In analysing the pointer years selected for the present study and of other authors, we obtained the same results for only one year – 1979 (Koprowski and Zielski 2002; Vitas 2004). In that year, weather conditions negatively influenced the radial growth of spruce from the analysed provenances at Wyszków, as well as spruce growing in the Olsztyn Lake District and western Lithuania. Both positive and negative characteristics of the remaining pointer years were unique to our area. According to Vitas (2001), differences in the designation of pointer years may result from the impact of factors other than climate and may be genetically determined. The reasons for the differences in pointer years could also be due to the differences in the ages of the analysed stands. From 1980 to 2000, the stands analysed in this study were between the ages of 20 and 40 years, while those analysed by other authors were between the ages of 180 and 200 years (Koprowski and Zielski 2002) and 100 and 120 years (Vitas 2004). In addition, these authors conducted their studies in spruce stands, not experimental plots, where due to the small size of an individual plot the impact of climatic conditions may differ. The growth rates of spruce in some pointer years (1995, 2000, 2001, 2004) of the analysed 20-year period cannot be explained by climatic anomalies. Therefore, they could have been related to other stress factors reducing radial growth, which occurred only locally.

5. Conclusions

– There is no evidence for differences in the dendroclimatic reaction of northern Norway spruce provenances to growth at the Wyszków experimental station.

– Precipitation uniformly influences the radial growth of Norway spruce, irrespective of the continentality gradient, while thermal conditions result in a nonspecific growth response related to the location of the stand.

– Increment in negative pointer years not confirmed by other published studies may be the result of factors other than climate, such as stand age and growth conditions, among others, at the study site.

Conflict of interest

None declared.

Acknowledgement and financial support

The study was financed by the State Forests National Forest Holding and carried out within the research project no. BLP-364.

References

- Bijak S. 2009. Climate-growth relationships of Norway spruce in north-eastern Poland. in: Levanič T. et al. (eds.) TRACE – Tree Rings in Archaeology. *Climatology and Ecology* 8: 98–103. ISSN 1610-0956.
- Bijak S. 2013. Climate signal in the radial growth of selected coniferous species from the Forest Experimental Station in Rogów. *Forest Research Papers* 74: 101–110. DOI: 10.2478/frp-2013-0010.
- Briffa K., Cook E.R. 1990. Methods of response function analysis. In: Cook E. Kairiukstis L.A. Methods of dendrochronology. Applications in the environmental sciences. Dordrecht. Boston. Kluwer Academic Publishers. pp. 240–247. ISBN 0-7923-0586-8.
- Broda J. 1998. Świerk w czasach historycznych. [Norway spruce in the historical times]. in: Boratyński A., Bugała W. (eds.). *Biologia świerka pospolitego* [Biology of the Norway spruce]. Instytut Dendrologii. Bogucki Wydawnictwo Naukowe. Poznań. pp. 25–40.
- Burczyk J., Giertych M. 1988. Wpływ suszy i innych czynników środowiskowych na wielkość przyrostu grubości świerka (*Picea abies* (L.) Karst.) różnych proveniencji. *Arboretum Kórnickie* 33: 181–209.
- Burczyk J., Giertych M. 1991. Response of Norway spruce (*Picea abies* (L.) Karst.) annual increments to drought for various provenances and locations. *Silvae Genetica* 40: 146–152.
- Cook E.R. 1985. A time series analysis approach to tree ring standardization. PhD thesis. University of Arizona.
- Cook E.R., Briffa K.R., Shiyatov S., Mazepa V. 1990. Tree-ring standardization and growth trend estimation. in: Cook E.R. Kairiukstis L.A.: Methods of dendrochronology: Applications in the environmental sciences. Dordrecht. Boston. Kluwer Academic Publishers. pp. 104–123. ISBN 0-7923-0586-8.
- Domańska W., Dubieniecka H., Dziel D., Karczewska K., Kielczykowska A., Kulik J. et al. 2009. Ochrona środowiska. Główny Urząd Statystyczny. Warszawa. 1–527. ISSN 0867-3217.
- Eilmann B., de Vries S. M. G., den Ouden J., Mohren G. M. J., Sauren P., Sass-Klassen U. 2013. Origin matters! Differ-

- ence in drought tolerance and productivity of coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) provenances. *Forest Ecology and Management* 302: 133–143. DOI: 10.1016/j.foreco.2013.03.031.
- Giertych M. 1972. Provenance differences in the time of spruce (*Picea abies* (L.) Karst.) flushing in Poland. *Arboretum Kórnickie* 17: 169–183.
- Giertych M. 2000. Wartość genetyczna świerka (*Picea abies* (L.) Karst.) z terenu poza jego naturalnym zasięgiem w Polsce. *Sylwan* 144: 19–31.
- Giertych M., Krupski P. 1996. Analiza produktywności polskich proveniencji świerka (*Picea abies* (L.) Karst.) na czterech krajowych powierzchniach doświadczalnych. *Arboretum Kórnickie* 41: 59–74.
- Grissino-Mayer H.D. 2001. Evaluating cross-dating accuracy: a manual and tutorial for the computer program COFECHA. *Tree Ring Research* 57: 205–221.
- Hensel W. 1980. Polska starożytna. Wyd. 2. Ossolineum. Wrocław. Warszawa. Kraków. Gdańsk. pp. 1–640.
- Holmes R.L. 1999. Dendrochronology Program Library (DPL). Users Manual. LTRR University of Arizona. Tucson.
- Koprowski M. 2008. Dendrochronologiczna analiza przyrostów rocznych świerka pospolitego (*Picea abies* (L.) Karsten) poza naturalnym zasięgiem a cechy biometryczne szyszek [Dendrochronological analysis of annual increments of Norway spruce (*Picea abies* (L.) Karsten) outside its natural range in comparison to biometric features of the cones]. *Sylwan* 152: 50–57.
- Koprowski M. 2013. Spatial distribution of introduced Norway spruce growth in lowland Poland: The influence of changing climate and extreme weather events. *Quaternary International* 283: 139–146. DOI: 10.1016/j.quaint.2012.04.020.
- Koprowski M., Vitas A. 2010. Growth/climate relationships in tree-ring widths of *Picea abies* in Lithuania and Poland. in: R. Przybylak et al. (eds.). *The Polish climate in the European context: An historical overview*. Dordrecht. Springer Science: 327–340. DOI 10.1007/978-90-481-3167-9.
- Koprowski M., Zielski A. 2002. Lata wskaźnikowe u świerka pospolitego (*Picea abies* (L.) Karsten) na Pojezierzu Olsztyńskim. *Sylwan* 146: 29 – 39.
- Koprowski M., Zielski A. 2003. Increment pattern in Norway spruce (*Picea abies* (L.) Karsten) along the continentality gradient. *Ecological Questions* 3: 113–117.
- Koprowski M., Zielski A. 2006. Dendrochronology of Norway spruce (*Picea abies* (L.) Karst.) from two range centres in lowland Poland. *Trees* 20: 383–390. DOI 10.1007/s00468-006-0051-9.
- Krupski P., Giertych M. 1996. Zmienność cech jakościowych polskich proveniencji świerka (*Picea abies* (L.) Karst.) na czterech krajowych powierzchniach doświadczalnych. *Arboretum Kórnickie* 41: 75–94.
- Matras J., Barzdajn W., Żybyra H., Szeligowski H. Buraczyk W., Kowalczyk J., Markiewicz P. 2006. Badania porównawcze populacyjnej i rodowej zmienności cech hodowlanych wybranych pochodzeń świerka pospolitego (*Picea abies* Karst.). Sprawozdanie końcowe tematu badawczego BLP – 238. Sękocin Stary. Instytut Badawczy Leśnictwa: 1–127.
- Mäkinen H., Nöjd P., Kahle H-P., Neumann U., Tveite B., Mielikäinen K. et al. 2003. Large-scale climatic variability and radial increment variation of *Picea abies* (L.) Karst.) in central and northern Europe. *Trees* 17: 173–184. DOI 10.1007/s00468-002-0220-4.
- Oleksyn J., Fritts H. 1991. Influence of climatic factors upon tree rings of *Larix decidua* and *L. decidua* × *L. kaempferi* from Pula. Poland. *Trees* 5: 75–82. DOI 10.1007/BF00227488.
- Rybniček M., Čermák P., Žid T., Kolář T. 2012a. Growth responses of *Picea abies* to climate in the central part of the Českomoravská Upland (Czech Republic). *Dendrobiology* 68: 21–30.
- Rybniček M., Čermák P., Kolář T., Žid T. 2012b. Growth responses of Norway spruce (*Picea abies* (L.) Karst.) to the climate in the South-Eastern part of the Českomoravská Upland (Czech Republic). *Geochronometria* 39: 149–157. DOI 10.2478/s13386-012-0003-7
- Savva Y. V., Schweingruber F. H., Kuzmina N. A., Vaganov E. A. 2002. Sensitivity of diameter growth to annual weather conditions in Scots pine provenances at a Central Siberian Location. *Silvae Genetica* 51: 49–55.
- Spiecker H. 2002. Tree rings and forest management in Europe. *Dendrochronologia* 20: 191–202. DOI: 10.1078/1125-7865-00016.
- Szafer W. 1931. The historical development of the geographical area of the spruce (*Picea excels* LINK) in Poland. *Przeł. Geogr.* 11: 1–8.
- Schmidt-Vogt H. 1977 (ed.). *Die Fichte*. 1. Taxonomie. Verbreitung. Morphologie. Ökologie. Waldgesellschaften. Parey. Hamburg u. Berlin. pp. 1–647.
- Środoń A. 1967. Norway spruce in the Quaternary Poland. *Acta Palaeobotanica* 8. 2: 3–59.
- Tryon R.C. 1939. Cluster analysis. Ann Arbor (Michigan) Edwards Brothers.
- Vitas A. 2001. Drought of 1992 in Lithuania and consequences to Norway spruce. *Baltic Forestry* 7: 25–30. ISSN 1392-1355.
- Vitas A. 2004. Tree rings of Norway spruce (*Picea abies* (L.) Karsten) in Lithuania as drought indicators: dendroecological approach. *Polish Journal of Ecology* 52: 201–210.
- Zielski A., Koprowski M. 2001. Dendrochronologiczna analiza przyrostów świerka pospolitego na Pojezierzu Olsztyńskim [A dendrochronological analysis of annual rings in Norway spruce of the Olsztyn Lake District]. *Sylwan* 145: 65–73.

Authors' contribution

M. K. – comparison of data, interpretation of results, writing, manuscript preparation, editing, proofreading, coordination. Sz. J. – literature review, verification of the data in the tables. L. Ch.-O. – dendrochronological analysis. J. K. – concept, assumptions.