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LOCAL CHRONOLOGIES AND REGIONAL DIVERSITY OF DENDROCHRONOLOGICAL SIGNAL OF DOUGLAS FIR IN POLAND

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Abstract: In Poland, 50 sites of Douglas fir were selected for which tree-ring chronologies were computed. Douglas fir in different parts of Poland has a specific increment rhythm, on the basis of which the four homogeneous dendrochronological zones were distinguished. The first zone (I) comprises Pomerania, Baltic coast, Warmia, and Mazuria (lowlands of northern Poland), the second zone (II) - Great Poland, Lower Silesia (lowlands of central Poland), the third zone (III) – the Sudetes and the Carpathian mountains, and the fourth zone (IV) – foothills of the Carpathians Mts., Roztocze, and the Świętokrzyskie Mts. (uplands of southern Poland). These areas are called the dendroclimatic zones because different thermo-pluvial conditions of the summer season were a cause of diversification of the Douglas fir increment rhythm, and in consequence of its chronology. A high similarity of site chronologies of a given region permitted to construct regional tree-ring chronologies for respective zones. Thermal conditions of the winter season (February - March) were the factor most strongly and similarly affecting radial increment of Douglas fir populations in the entire territory of Poland. This factor caused that all chronologies showed many similar traits in their progress. This fact permitted to construct the supra-regional (all-Polish) tree-ring chronology for this tree species. It comprises the period from 1900 to 2000, and it is a good standard for dating Douglas fir wood samples originating from the area of Poland.

Keywords: Douglas fir, dendrochronology, dendroclimatology, tree-ring chronology, dendroclimatic zones, Poland

1. INTRODUCTION

Construction of present-day tree-ring chronologies for different tree species is a common practice in the world. They form an ever denser network covering almost all continents. The present-day chronologies form the basis for working out the historic chronologies, as well as for a broadly understood ecological research. For some time, also in Poland chronologies are being constructed for different tree species (Feliksik, 1990; Ważny, 1990; Zielski, 1997; Wilczyński, 1999; Zielski *et al.*, 2001; Szychowska-Krąpiec, 1997; Krąpiec, 1998; Bruchwald, 2000; Zielski and Koprowski, 2001; Wilczyński and Skrzyszewski, 2002b, 2003; Chojnacka-Ożga, 2002; Feliksik and Wilczyński, 2000a, 2001, 2002b; Szychowska-Krąpiec and Krąpiec, 2005).

Douglas fir is a foreign species in Poland. It was planted in the late 19th century, mainly in northern, western and southern Poland. Trees had to adapt to environmental conditions different from those prevailing in northwestern America, a native region of Douglas fir. Presently the oldest Douglas fir trees in Poland are about 150 years old. In the nearest future they will disappear from Polish forests in the process of timber harvesting. However, the old trees are being gradually replaced by a young generation. Our Douglas fir tree-ring network will be in future the oldest part of the dendrochronological database for this species, comprising a considerable part of Poland.

Tree-ring width is mainly a result of the effect of the meteorological factor. Each year a unique arrangement of weather conditions affects the activity of vascular cambium. This way a tree forms its individual increment pattern, so called an individual chronology. In the case of

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trees of a given species growing in a small area the increment responses are very close to each other, and therefore the tree-ring widths of individual trees are very similar (Fritts, 1976; Cook *et al.*, 1990). On their basis a local pattern of radial increment is formed. If the growth activity of trees of a given species is molded at the same time and in a similar environment, then their increment patterns may be used for dating of wood samples, and may also constitute a valuable material for delimiting areas homogeneous in respect of climate. In the case of large areas, differing strongly in climate, the differences among tree-ring chronologies are very distinct, and thus they may be separated relatively easily (Biondi and Visani, 1996; Mäkinen *et al.*, 2000, 2002; Briffa *et al.*, 2002a, b; Tuovinen, 2004; Piovesan *et al.*, 2005).

Our research hypothesis assumed that the territory of Poland is sufficiently diversified climatically that the increment responses of Douglas fir trees growing in different parts of the country would show a different increment rhythm. On the other hand we assumed, that there exist factors of a supra-regional character, and that their influence on tree growth is strong enough to make the construction of supra-regional increment patterns possible. The existence of this paradox was pointed out by dendrochronological studies on native tree species (Ważny, 1990; Feliksik, 1993; Krąpiec, 1998; Wilczyński, 1999; Wilczyński *et al.*, 2001; Wilczyński and Skrzyszewski, 2002a, 2003).

The purpose of this study was to construct a network of local Douglas fir tree-ring chronologies comprising northern, western, and southern Poland, and also to construct regional and supra-regional tree-ring chronologies for this tree species. Besides, an attempt was made to separate regions, dendrochronologically uniform, searching for reasons which caused differences in increment responses of Douglas firs.

2. MATERIAL AND METHODS

Fifty populations of Douglas fir were selected in the territory of Poland (**Fig. 1**). Characteristics of individual stands and the basic statistics of the chronology are presented in **Table 1**. In each stand, 25 healthy dominant trees were chosen. From the stem of each tree one increment core was taken 1.3 m above the ground. On each core, the width of tree annual rings was measured, determining the year of production of each tree-ring. Thus 1250 tree-ring width series were obtained.

The correctness of tree-ring dating was verified using the computer program COFECHA (Holmes, 1986). For each site a tree-ring chronology was formed. Then, using the computer program ARSTAN (Cook and Holmes, 1986) each tree-ring width series was standardized according to the formula:

$$I_i = X_i \cdot Y_i^{-1} \qquad (2.1)$$

where: X – tree-ring width, Y – value of the smoothed curve, i – year.

Then, each indexed tree-ring series was modelled as an autoregressive process (AR) where the order is selected for the individual series by first-minimum Akaike Information Criterion. Program ARSTAN produces chronology from tree-ring measurement series by detrending and indexing the series, then applying a robust estimation of the mean value function to remove effects of endogenous stand disturbances (Cook and Holmes 1986). This chronology is stated as a residual chronology, and it is devoid of autocorrelation.

This way their short-term variation, determined mainly by the meteorological factor, was brought into prominence. On the basis of the tree-ring width series and residual series the tree-ring chronology and standardized chronology were constructed for each site (50).

To classify the chronologies (variables), to estimate differences and similarities between them, and also to identify factors determining chronology variation, the multidimensional analysis of principal components, cluster analysis (Ward, 1963), linear correlation, and convergence coefficient (Eckstein and Bauch, 1969) were used. The convergence coefficient GL was calculated according to the formula:

$$GL = 100 \cdot m \cdot (n-1)^{-1} [\%] \qquad (2.2)$$

where: m – number of chronology sections of similar direction of progress, n – number of years compared.

3. RESULTS

The similarity between tree-ring width series in a given site was very high. In each case the value of the coefficient of correlation between the tree-ring width series of individual trees and the mean site chronology was highly statistically significant (p<0.01). This showed a high homogeneity of increment responses of trees in each population. The site tree-ring chronologies, constructed on the basis of these series, were characterized by a high representativeness. Also the site tree-ring chronologies turned out to be similar (**Fig. 2**). In most of them

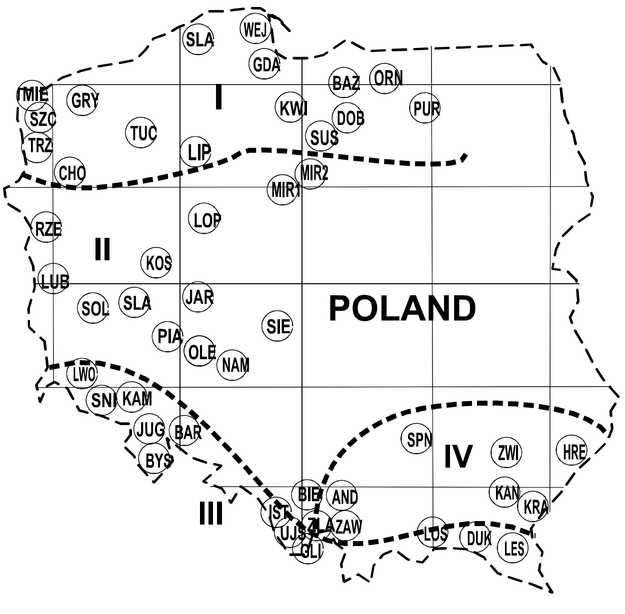

Fig. 1. *Map of collection sites of Douglas fir in Poland. Three-letter site are the same as in* ***Table 1****. I, II, III, IV the dendroclimatic zones of Douglas fir.*

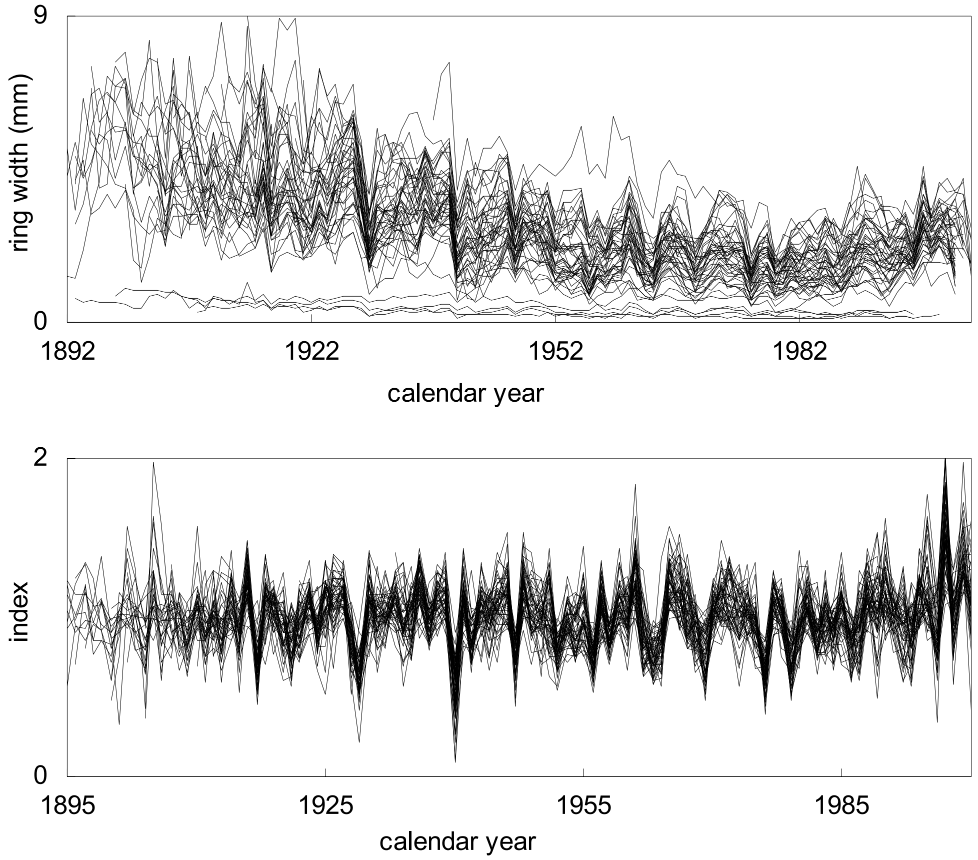

Fig. 2. *Site tree-ring chronologies (top figure) and site residual chronologies (bottom figure) of Douglas fir.*

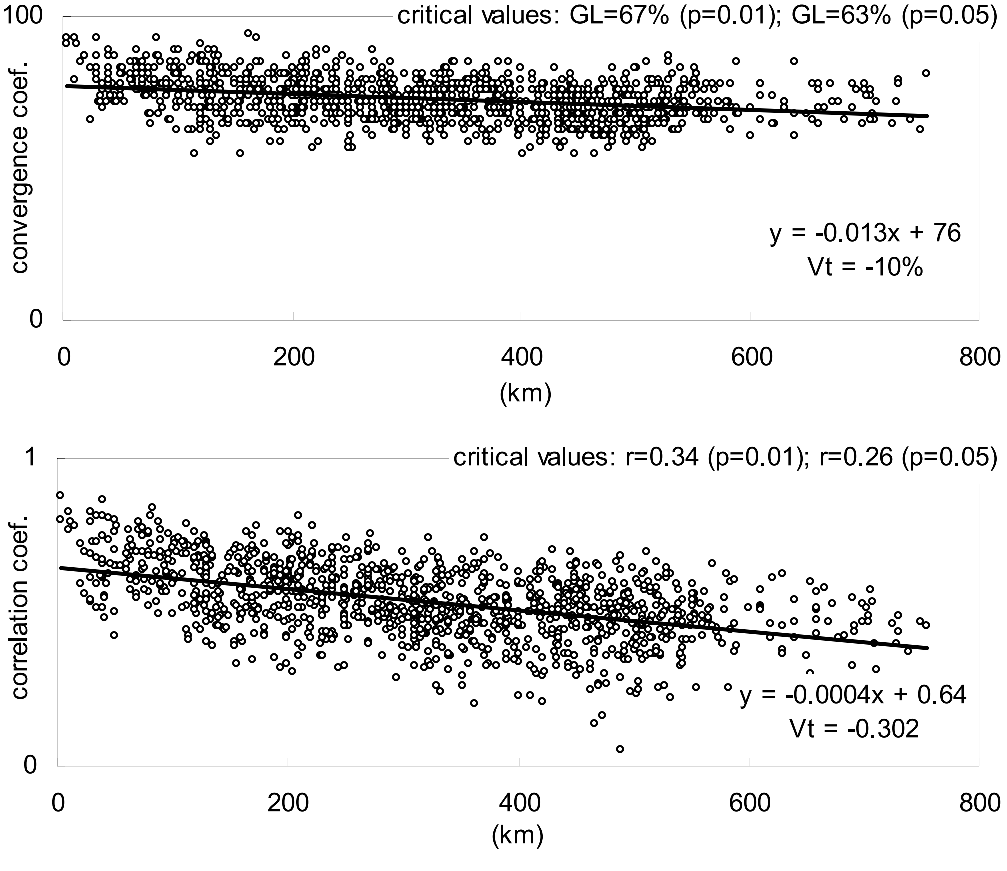

Fig. 3. *Relationship between correlation coefficient and distance of sites (top figure); relationship between convergence coefficient and distance of sites (bottom figure); V_t – value of trend.*

Table 1. *Characteristics of research sites of Douglas fir and statistics of local tree-ring chronologies (A) and indexed chronologies (B).*

Forest District Forest Division	Site Code	Elevation	Site Type	Chronology length	MRW (mm)	MS (%)	MI	MS (%)	r M
					A		B		
Nowa Wieś Purda Leśna 243a	PUR	200	FBF	1903-1998	2.65	23	1.0	22	0.69
Orneta Pieniężno 19c	PIE	150	FMBF	1903-2003	2.76	18	1.0	23	0.65
Orneta Bażyny 462	BAZ	150	FMBF	1914-2003	3.40	19	1.0	24	0.84
Dobrocin Morąg 240a	DOB	150	FMBF	1903-2003	3.01	21	1.0	29	0.82
Susz Uroczysko 5g	SUS	100	FBF	1893-2003	2.39	24	1.0	31	0.76
Kwidzyn Gonty 237f	KWI	70	FBF	1892-2001	2.77	21	1.0	25	0.73
Gdańsk Renuszowo 94c	GDA	146	FBF	1905-2001	2.67	22	1.0	25	0.78
Sławno Jarosławiec 85c	SLW	120	FMBF	1897-2001	2.81	14	1.0	18	0.82
Wejherowo Domatowo 126d	WEJ	100	FBF	1915-2002	3.51	19	1.0	24	0.76
Tuczno Rzeczyce 101g	TUC	150	FBF	1900-2002	2.32	19	1.0	24	0.81
Gryfice Świerzno 645g	GRY	60	FMBF	1908-1998	0.51	20	1.0	24	0.76
Rzepin Kunowice 190d	RZE	100	FBF	1899-2001	2.03	24	1.0	36	0.66
Choszczno Ziemomyśl 883g	CHO	100	FBF	1903-2001	3.22	21	1.0	28	0.74
Trzebież Podymin 342i	TRZ	50	FMBF	1920-2000	2.33	19	1.0	22	0.83
Lasy Komunalne Szczecin 54b	SZC	40	MMCF	1910-2001	2.05	24	1.0	29	0.66
Międzyzdroje Warnowo 62f	MIE	10	FMBF	1893-2001	2.10	19	1.0	24	0.76
Lipka Białobłocie 153d	LIP	120	MMCF	1907-2001	2.75	24	1.0	29	0.82
Miradz Młyny 109a	MIR1	105	FMBF	1899-2001	2.38	24	1.0	26	0.77
Miradz Młyny 71n	MIR2	100	FMBF	1895-1999	3.09	22	1.0	27	0.76
Lubsko Jeziory Dolne 24i	LUB	86	FMBF	1898-2001	2.71	21	1.0	23	0.74
Nowa Sól Mirocin 176h	SOL	95	FMBF	1907-2001	2.26	22	1.0	29	0.68
Sława Śląska Stare Strącze 331l	SLA	87	FBF	1911-2001	2.51	23	1.0	28	0.65
Kościan Olejnica 256h	KOS	80	FMBF	1904-2001	2.41	18	1.0	21	0.69
Jarocin Cielcza 180a	JAR	90	FMBF	1917-2001	2.21	23	1.0	28	0.82
Łopuchówko Wojnowo 169c	LOP	86	FBF	1893-2000	0.34	22	1.0	27	0.76
Piaski Sowiny 36c	PIA	200	FBF	1919-2002	2.97	21	1.0	25	0.77

Table 1. *Continuation. Characteristics of research sites of Douglas fir and statistics of local tree-ring chronologies (A) and indexed chronologies (B).*

Forest District Forest Division	Site Code	Elevation	Site Type	Chronology length	MRW (mm)	MS (%)	MI	MS (%)	r M
					A		B		
Namysłów Niwki 105c	NAM	130	FMBF	1900-2003	2.84	17	1.0	22	0.86
Sieradz Reduchów 114f	SIE	160	FCF	1921-2002	2.25	17	1.0	25	0.73
Oleśnica Dąbrowa 63j	OLE	150	FBF	1905-2003	2.91	18	1.0	22	0.76
Bystrzyca Kłodzka Lasówka 309c	BYS	750	MMBF	1895-2001	2.93	15	1.0	19	0.69
Bardo Śląskie Zębowina 225g	BAR	450	MBF	1909-2001	2.91	18	1.0	22	0.86
Jugow Ścinawka D. 118f	JUG	400	MMBF	1895-2001	2.72	18	1.0	23	0.76
Śnieżka Strużnica 89b	SNI	650	MMBF	1893-1997	2.38	17	1.0	21	0.69
Kamienna Góra Podlesie 268d	KAM	600	MMCF	1892-2001	2.43	18	1.0	22	0.76
Lwówek Śląski Gradówek 308k	LWO	300	UBF	1893-2001	2.85	19	1.0	23	0.83
Andrychów Żarnówka 123a	AND	650	MBF	1919-1998	3.43	16	1.0	19	0.75
Bielsko Biała Wapienica 124	BIE	550	MMBF	1902-1998	2.70	18	1.0	24	0.73
Ujsoły Glinka 172a	GLI	700	MBF	1909-1998	3.11	14	1.0	19	0.73
Ujsoły Złatna 58b	ZLA	660	MBF	1900-1998	3.49	16	1.0	18	0.76
Ujsoły Złatna 59a	UJS	700	MBF	1932-2002	2.79	16	1.0	21	0.74
Wisła Istebna 29b	IST	700	MMBF	1906-1999	0.28	19	1.0	22	0.72
Sucha Mosorne 68y	ZAW	600	MMBF	1891-2001	2.12	17	1.0	24	0.76
Łosie Brunary 47b	LOS	600	MBF	1911-2001	2.78	17	1.0	22	0.78
Dukla Odrzykoń 84b	DUK	450	UBF	1926-2002	3.11	19	1.0	23	0.67
Lesko Monasterzec 26a	LES	450	UBF	1915-2002	3.39	16	1.0	23	0.79
Kańczuga Tarnawka 90a	KAN	350	UBF	1909-2002	3.20	19	1.0	25	0.78
Krasiczyn Hołubla 101a	KRA	380	UBF	1909-2001	3.01	16	1.0	24	0.67
Tomaszów Lub. Siedliska 356d	HRE	200	FBF	1915-2002	2.80	16	1.0	19	0.77
RPN Zwierzyniec 138f	ZWI	270	UBF	1921-2002	3.05	18	1.0	19	0.76
ŚPN Podlesie 165i	SPN	380	UBF	1937-2003	3.96	17	1.0	21	0.68

MRW – mean ring width, MI – mean index, MS – mean sensitivity, r M – correlation coefficient between site chronology and master chronology, FBF – fresh broadleaved forest, FMBF – fresh mixed broadleaved forest, MMCF – moist mixed coniferous forest, FCF – fresh coniferous forest, MMBF – mountain mixed broadleaved forest, MBF - mountain broadleaved forest, MMCF - mountain mixed coniferous forest, UBF – upland broadleaved forest a declining trend, typical for conifers, was found. However, these chronologies differed in respect of the width of the mean tree-ring, first order correlation, and the mean sensitivity (**Table 1**). It is interesting that coefficients of variation and the mean sensitivities of chronologies did not show statistically significant correlation ($r=0.022$, $p>0.05$). Therefore, the long- and short-term variations of the tree-ring chronologies were the independent variables. A high autocorrelation of the first order was a characteristic trait of the tree-ring chronologies, which indicated that there was a strong relationship between traits of two consecutive tree-rings.

The process of transformation of tree-ring chronologies caused that the mean increment index of the residual chronology was stabilized on the level of one, while the autocorrelation was lowered almost to zero (**Table 1**). In chronologies, the trend and most of a long-term fluctuation were removed (**Fig. 2**). The indexing caused that a short-term variation became emphasized, and a long-term variation was strongly reduced. Contrary to tree-ring chronologies the coefficients of variation and sensitivity of the residual chronologies showed a very strong correlation ($r=0.914$, $p<0.001$). Almost a zero value of autocorrelation showed a lack of relationship between two consecutive increment indexes, which is of a significant importance in the analyses of the climate-increment type. Besides, each site residual chronology retained its primary direction of annual value changes, characteristic for tree-ring chronology. Each of them was also strongly correlated ($p\leq0.01$) with the standard chronology being the mean of all site chronologies (**Table 1**). This fact indicated a high convergence of changes in mean radial increments of investigated populations of trees. This was also confirmed by a similar progress of site residual chronologies (**Fig. 2**). A certain supra-regional factor must have had a similar influence on increment of all Douglas fir trees.

However, values of the coefficients of correlation of residual chronologies decreased with increase of the distance between sites (**Fig. 3**). This confirmed a known phenomenon of an inverse relationship between the chronology similarity and the distance between them (Müller-Stoll, 1951; Ermich, 1960; Feliksik, 1990; Zielski, 1997; Feliksik and Wilczyński, 1996, 2002b, 2003a, b; Wilczyński and Skrzyszewski, 2002a). There were, however, cases when site chronologies did not show statistically significant similarity (**Fig. 3**). The largest number of such cases occurred between chronologies situated 100 – 500 km apart. While the chronologies situated closer to each other (<100 km), and situated over 500 km apart

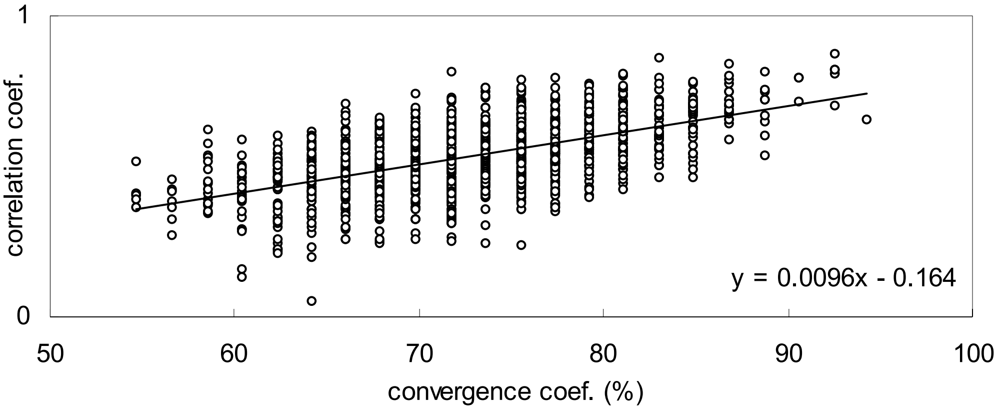

Fig. 4. *Relationship between correlation and convergence coefficients for each of two chronologies, adequately - tree-ring and residual chronologies.*

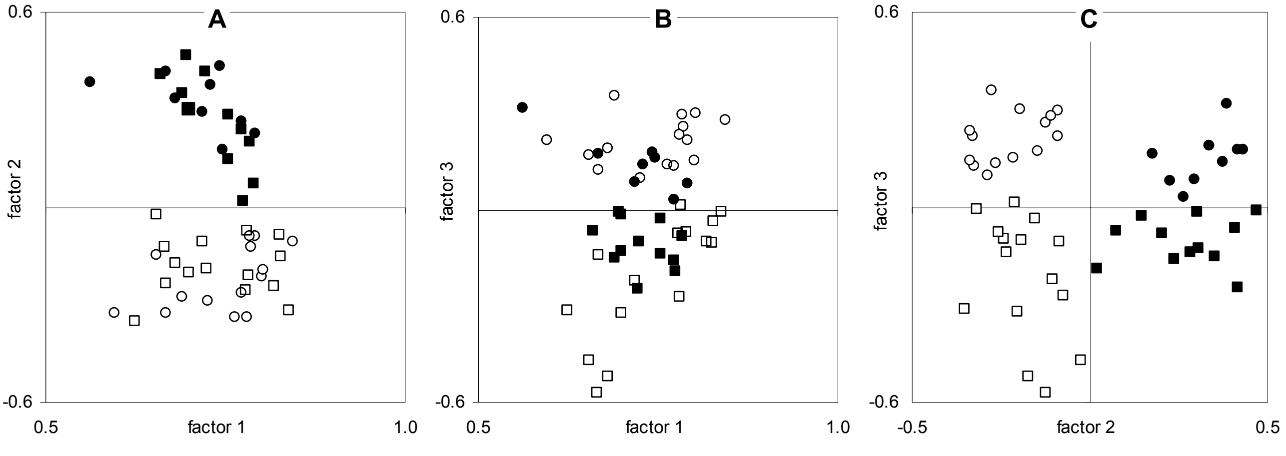

Fig. 5. *Location of the residual chronologies in relation to factor loadings. Chronologies from: Pomerania, Baltic coast, Warmia, and Mazuria - zone I (white dots); Great Poland, Lower Silesia - zone II (white squares); Sudetes and Carpathian Mts. – zone III (black squares); Roztocze, and Świętokrzyskie Mts. - zone IV (black dots) (see* ***Fig. 1****).*

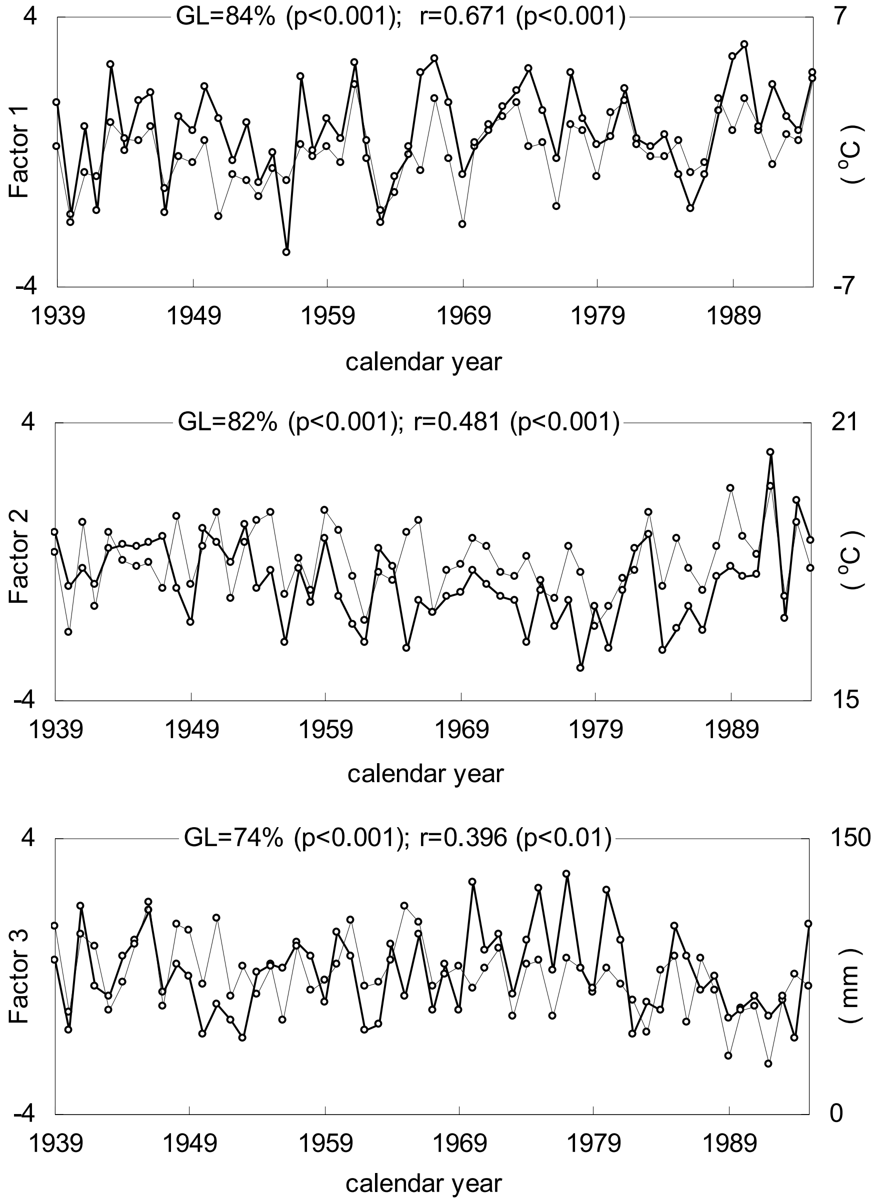

Fig. 6. *Scores of first factor (thin line) and the mean February-March temperature (thick line) (top figure); scores of second factor (thin line) and mean July-August temperature (thick line) (middle figure); scores of third factor (thin line) and July-August total precipitation (thick line) (bottom figure).*

very frequently showed a very high similarity. Such a distribution of values of both coefficients indicated a specific relationship in spatial variation of chronologies. Distant regions must have certain characteristics determining variation of tree increment in a similar manner. The identification of these regions, based on the correlation and similarity alone, is not easy, and the identification of the characteristics is simply impossible. Besides, the information about relationships between chronologies, presented by both coefficients, was not homogeneous. It increased at relatively small (< 100 km) and relatively large (> 500 km) distances between sites (**Fig. 4**).

The results of the analysis of principal components of residual chronologies showed that the three distinguished components explained 66% of total variance of the investigated chronologies. The first component of the highest eigenvalue (27.2) explained about 54%, the second (3.5) 7%, and the third (2.4) 5%. The first component was strongly positively correlated with all chronologies (**Fig. 5A**, **B**). Correlations between the remaining two components and the variables were weaker, but these components were responsible for differentiation of chronologies. The second component permitted to distinguish two groups of chronologies. The first group included chronologies from lowlands of northern parts (Pomerania, Baltic coast, Warmia, Mazuria – zone I) and central (Great Poland, Lower Silesia – zone II) of Poland. The second group included chronologies from mountain areas, submontane zone (the Sudetes and the Carpathian Mts. – zone III) and uplands of southern Poland (foothills of the Carpathians Mts., Roztocze, and the Świętokrzyskie Mts. – zone IV) (**Fig. 5B**, **Fig. 1**). The third component also permitted to distinguish two, but different, groups of chronologies. The first comprised chronologies from Pomerania, Baltic coast, Warmia, and Mazuria (zone I), as well as from foothills of the Carpathians Mts., Roztocze, and the Świętokrzyskie Mts. (zone IV). The second component comprised chronologies from the Sudetes and

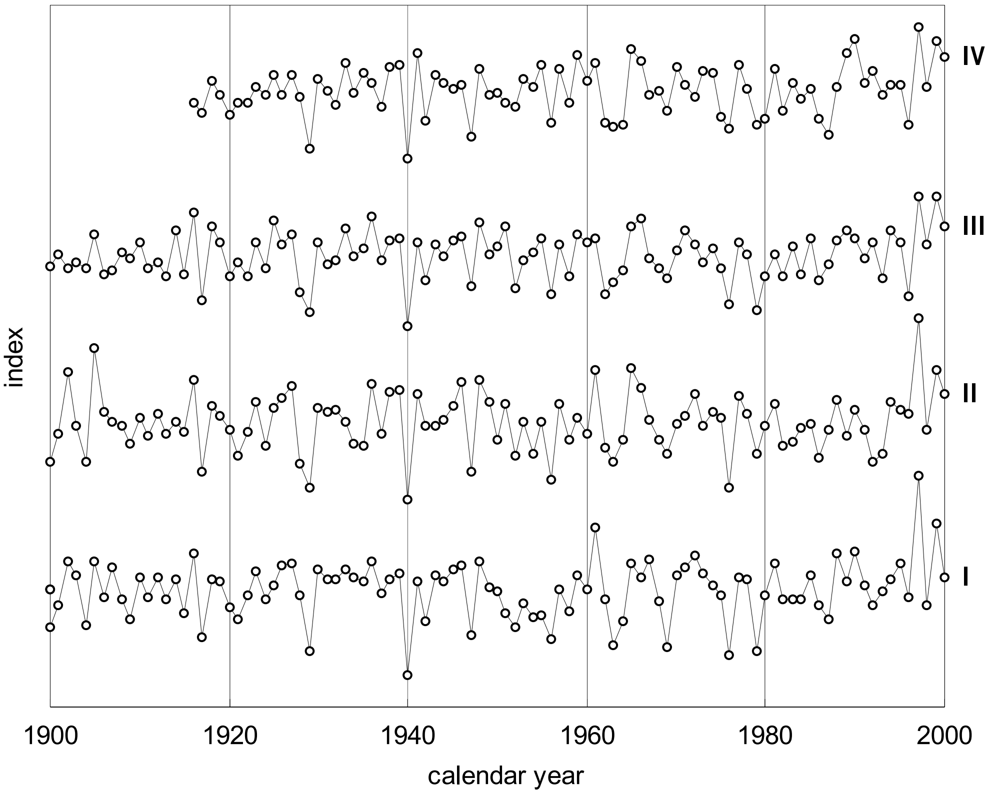

Fig. 7. *Residual chronologies of Douglas fir of 4 zones.*

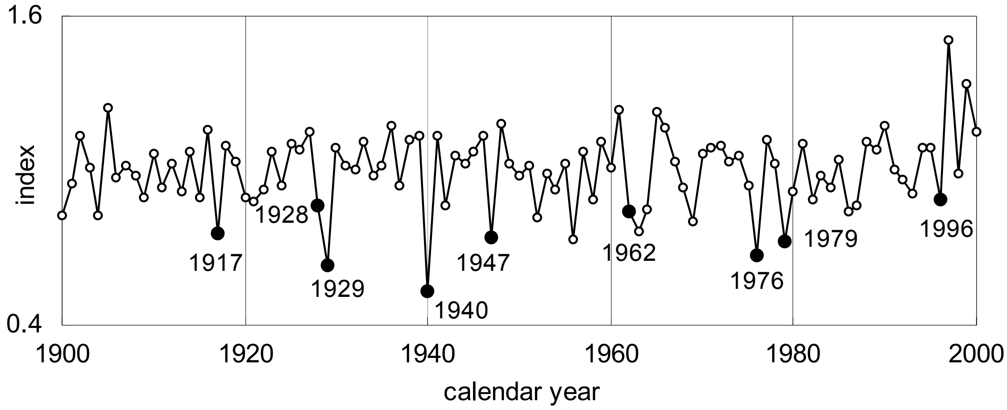

Fig. 8. *Residual chronology of Douglas fir for Poland; years of a rapid strong lowering of tree-ring width (black dots).*

the Carpathian Mts. (zone III), and Great Poland, and Lower Silesia (zone II) (**Fig. 5C**, **Fig. 1**).

The residual chronologies showed variation determined mainly by meteorological conditions, a most variable element of environment. And this was the direction of searching with the aim to identify the character of distinguished factors. The comparison between the component values and the climatic data showed that the first principal component was most strongly correlated ($r=0.671$, $p<0.001$), and was most convergent (GL=84%, $p<0.001$) with mean temperature of the period February – March (**Fig. 6A**); the second component ($r=0.481$, $p<0.001$; GL=82%, $p<0.001$) with mean temperature of the period June – August (**Fig. 6B**), and the third component ($r=0.396$, $p<0.01$; GL=74%, $p<0.001$) with total precipitation of the period June – August (**Fig. 6C**). Therefore, the first component, most strongly determining the variation of all chronologies, may be designated as the thermal conditions of winter, the second as the thermal conditions of summer, and the third one as the pluvial conditions of summer. The radial increment of all Douglas fir populations was strongly and similarly determined by temperature of late winter, while a weaker influence had thermo-pluvial conditions of full growing season, which at the same time diversified the increment rhythm of trees.

The distinguished areas, dendrochronologically homogeneous, may be designated as the dendroclimatic zones, because climate is the factor modeling the radial increment of Douglas fir. The first zone comprises lowlands of northern Poland, the second zone - lowlands of central Poland, the third zone - mountains of southern Poland, and the fourth zone - uplands of southern Poland (**Fig. 1**).

Table 2. *Correlation coefficients between residual chronologies and convergence coefficients [%] (bold) between tree-ring chronologies.*

Zone	I	II	III	IV
I	x	0.857*	0.794*	0.756*
II	**90.5***	x	0.808*	0.683*
III	**78.6***	**82.1***	x	0.815*
IV	**82.1***	**76.2***	**84.5***	x

* - Significant values (p≤0.01)

For each of the distinguished zones the regional standard tree-ring chronology was created on the basis of site chronologies (**Fig. 7**). The cluster analysis of correlation and convergence of regional chronologies showed that they were highly similar (**Table 2**, **Fig. 9**). The chronologies of areas situated close to each other of zones I and II, and also of zones III and IV were characterized by the greatest similarity (**Table 2**, **Fig. 9**). It also turned out that chronologies of very distant zones I (northern lowlands) and IV (uplands), as well as zones II (central lowlands) and III (mountains) were characterized by a high coefficient of convergence (**Table 2**). This was confirmed by earlier results of the analyses of correlation and convergence of chronologies (**Fig. 3**), and the analysis PCA (**Fig. 5**). It turned out that summer precipitation similarly modeled the variation of chronologies of trees originating from these seemingly different regions. The summer precipitation must have had a similar effect on radial increment of Douglas fir in zones I and IV as well as in zones II and III.

A very high similarity among regional chronologies created the basis for construction of one supra-regional chronology (**Fig. 8**). All points characteristic for increment of all investigated Douglas firs were brought into prominence in this chronology. These were the years of a rapid strong lowering of tree-ring width, also characteristic for each of the four regional chronologies (**Fig. 7**). They are marked on **Fig. 8** as black points, and they constitute the control points in dating samples of Douglas fir wood. These years were characterized by a very frosty and long winters.

4. DISCUSSION

Douglas fir growing under natural conditions of its range on the American continent is characterized by a great variation of morphological and physiological traits of its two extreme ecotypes: the mountain ecotype from the Rocky Mountain region, and the coastal ecotype from the Pacific slope (Harlow *et al.*, 1979). This variation also occurs among populations introduced to the European continent. Beside morphological differences it also concerns rate of growth, resistance to draught and frost, and seasonal diversification of development rhythm (Maciejowski, 1951; Bellmann and Schönbach, 1964; Białobok and Mejnartowicz, 1970; Chylarecki, 1976). Also this variation was found within the progeny of a single tree. This showed a wide range of tree response to environmental conditions and individual plasticity (Schober, 1963; Białobok and Mejnartowicz, 1970; Mejnartowicz, 1976). These observations, however, have not been confirmed in the variation of the increment rhythm of trees growing within a partial population limited in area. However, these differences are clearly evident among different partial populations, frequently located not too far away from one another. According to some authors, working on the assessment of Douglas fir acclimatization experiments, the climatic conditions, as a most variable and at the same time stress generating environmental element strongly determining the condition and growth of trees, have a crucial effect on the success of Douglas fir introduction (Borowiec, 1965; Chylarecki, 1976). Old Douglas fir trees, growing at the present time in Poland, underwent tests enforced upon them by the environment, and in consequence a valuable material has been selected, which may be used to widen our knowledge about this tree species. History of tree response to environmental stimuli is preserved in a sequence of annual increments of the vascular tissue. The analysis of variation of values of radial increments of trees in relation to meteorological conditions, prevailing in a given area, permits to recognize the effect of climate on diameter growth of trees, and to verify and widen our knowledge about tree requirements in this respect. In this study, however, we did not wish to be concerned with a detailed interpretation of the climate – increment relationships. These relationships have been widely motivated in numerous papers dealing with ecology of Douglas fir (Suchocki, 1926; Schulman, 1947; Maciejowski, 1950, 1951; Jahn, 1955; Schober, 1963; Fritts, 1965, 1974; Białobok and Chylarecki, 1965; Tumiłowicz, 1967; Yao, 1971; Mejnartowicz, 1976; Chylarecki, 1976; Bellon *et al.*, 1977; Harlow *et al.*, 1979; Schober *et al.*, 1983; Feliksik and Wilczyński, 1998a,b, 2000b, 2002a, 2003a,b; Biondi, 2000).

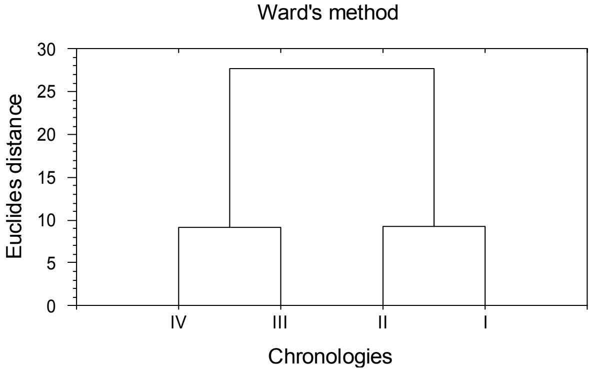

Fig. 9. *Hierarchical clustering dendrogram of residual chronologies of 4 zones over the common period 1916-2000.*

It should be mentioned that research concerning this species hitherto, and confirmed during this study, have indicated that air temperature of winter is the main factor similarly modeling magnitude of tree diameter increment in the entire area of Poland (Feliksik and Wilczyński, 1998a,b, 2002a, 2003a,b, 2004). This is the strongest climatic signal embedded in Douglas fir tree-rings. The increment response of Douglas fir to frosty and long winters is the same in every place of Poland. Therefore, conditions of the winter season may be successfully reconstructed on the basis of the Douglas fir tree-ring chronology.

Also precipitation and air temperature prevailing during summer months have a significant effect on Douglas fir increment. However, the sensitivity of trees to these conditions is different in each region of Poland. These facts are reflected in the diversification of the climate – increment interaction, and in consequence in characteristics of tree-ring chronology. Thus the diversification of Douglas fir tree-ring chronology results from its variable sensitivity mainly to a regional thermo-pluvial factor. The diversification of summer climatic conditions in Poland turned out to be significant enough for this species as to be reflected in increment responses, but it was decidedly weaker than temperatures prevailing in winter.

A close relationship between Douglas fir radial increment and temperature as well as precipitation of the summer season distinctly corresponds with regional diversification of these climatic elements in the area of Poland. General climate-radial increment models are in the entire Poland very similar (Feliksik and Wilczyński, 2004). The differences that occur mainly concern the force of influence of individual meteorological elements, especially those which most strongly model the metabolic processes, and in consequence decide on activity of the vascular cambium

In areas of a strong diversification of climatic conditions significant for tree growth the variability of tree growth responses is very clear. This has been confirmed by many othrer studies (Biondi and Visani, 1996; Mäkinen *et al.*, 2000, 2002; Briffa *et al.*, 2002a,b; Tuovinen, 2004; Piovesan *et al.*, 2005). It has turned out that also the territory of Poland is climatically diversified enough to find its reflection in increment activity of Douglas fir. The arrangement of the distinguished dendroclimatic zones in Poland is latitudinal, strongly corresponds with geographic- climatic regions, and is very similar to zones distinguished for Scots pine (Wilczyński *et al.*, 2001).

5. CONCLUSIONS

1. The Douglas fir tree-ring chronology network, developed during this study, represents local rhythms of increment of this species in Poland. The site tree-ring chronologies are the increment standards of local range for this tree species.
2. Results of this study have confirmed the hypothesis about possibility of construction in Poland of high quality Douglas fir increment standards, not only of a regional range, but also of a supra-regional (all-Polish) scale.
3. It happens that chronologies of sites located at short distance from each other show a small similarity. Thus the regional chronologies are a better standard for dating Douglas fir wood samples originating from a given climatic region.
4. A high quality is also presented by a supra-regional tree-ring chronology, being an increment standard of Douglas fir for the entire Poland.
5. In spite of a certain diversification of the similarity among local chronologies the area of Poland is for Douglas fir the dendrologically homogeneous area. This has been decided by a single climatic element, i.e. by temperature of winters. It is the strongest, and at the same time a highly homogeneous signal embedded in tree-rings.
6. Thermo-pluvial conditions of the summer season diversify the increment rhythm of Douglas fir in Poland. Their specific effect on variation of increment responses of Douglas fir permitted to distinguish four dendroclimatic zones for this species in Poland.

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