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Dendroclimatic regions of Douglas fir *Pseudotsuga menziesii* (Mirb.) Franco in western and northern Poland

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Abstract: This study concerned 26 forest stands with Douglas fir situated in Lower Silesia, Great Poland, Pomerania, Warmia and Masuria. Each stand was represented by 24 trees. From each tree an increment core was taken by Pressler's borer. The principal components analysis showed that the first three principal components accounted for 73% of the variation of chronologies in total. The first principal component was the most convergent with the mean air temperature curve for January–March, the second with the total precipitation for June–August, and the third with the mean temperature for June–August. The first principal component always integrated the chronologies and decided on a similar rhythm of changes in the tree-ring widths. The annual variation of tree-ring widths was also affected by precipitation in summer (June–August), but this differentiated the chronologies. This was reflected by the dispersion of chronologies in respect to the eigenvectors of the second principal component. The third principal component also differentiated the chronologies. Separate groups were formed by the most eastern and the most western localities of the territory under investigations. Thus the Douglas fir growth reactions were mainly affected by the thermal and pluvial conditions of summer and, to a lesser, degree by the thermal conditions of winter. On the basis of these results it was possible to distinguish the dendroclimatically homogeneous regions in western and northern Poland.

Additional key words: dendroecology, dendrochronology, *Pseudotsuga menziesii*

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Introduction

The introduction of forest trees of foreign origin carried out in Europe at the turn of the 19th century included many species native to North America. Among them Douglas fir was the most abundantly represented species in the experimental plots. Today, this tree species has become naturalized in the forests of Central Europe thanks to natural as well as artificial regeneration. It has adapted to local climatic and biocenotic conditions (Białobok and Chylarecki 1965; Chylarecki 1976). Many Douglas fir introduction plots of the 19th century are situated within present borders of Poland. They are mainly grouped in the western and northern parts of the country. At present over 100-year-old trees are a very good material for studies aiming at the estimation of the effect of climatic conditions on their growth and spatial variability of the conditions that determine their radial increments.

The radial increment is a result of the reaction of a tree to many factors deciding about its metabolic processes. Among these factors, the signal resulting from weather conditions is the most clearly registered one in annual variation of the wood layer formed (Ermich 1955; Douglass 1971; Fritts 1976). Dendroclimatological analysis of long tree-ring series permits to determine the relationships between individual climatic elements and the size of radial increments (Fritts 1976; Schweingruber 1983).

The purpose of this study was to determine the effect of climatic conditions on the variation of radial increment of Douglas fir growing in western and northern parts of Poland. We expected that the variability of thermal and pluvial conditions in this area will be reflected in growth reactions of Douglas fir trees.

Methods

The Douglas fir studied originated from Lower Silesia, Lowland of Great Poland, Pomerania, Warmia and Masuria. These regions differ in respect of thermal and pluvial regimes (Woś 1999).

Each of the 26 partial populations of Douglas fir investigated was represented by 24 trees. The data concerning the sites and stands is shown in Table 1. Using the increment borer the core was taken from each tree, 130 cm above the ground. Then the tree-ring widths were measured. Data series from each tree, called the dendroscales, were verified by the COFECHA computer program (Holmes 1986). On their basis, using the ARSTAN program (Cook and Holmes 1986), the indexed dendroscales were computed. The purpose of this indexing was to eliminate from the dendroscales the long-term variation of tree-ring widths caused by the aging of trees and the influence of non-climatic factors, and to bring out the variation mainly caused by meteorological conditions.

On the basis of the indexed dendroscales the so-called local indexed chronologies were developed. This was accomplished by averaging of relative values of tree-ring widths in each year. These chronologies represented the growth pattern of Douglas fir in a given locality.

To estimate the diversification of the radial increment rhythm of Douglas fir in different regions its indexed chronologies were used as variables in a principal components analysis. To determine the character of the factors determining the variation of chronologies the coefficient of agreement (GL) was used (Huber 1943, Eckstein and Bauch 1969), and the scores of principal components were compared with the values of various climatic elements of individual months or seasons.

Temperature and precipitation data were obtained from the meteorological station in Koszalin.

Results

The principal components analysis showed that the first three components (PC1, PC2, PC3) accounted for 73% of chronology variation in total. The first component accounted for 61%, the second for 8%, and the third for 4%. The scores of individual components did not correlate with one another, and showed a complete lack of agreement. It had to be concluded that they described different factors affecting the variation of chronologies. In order to determine these factors the analysis of agreement between scores of the three principal components (PC1, PC2, PC3) and the mean values of air temperature and total precipitation was made. The highest coefficients of agreement were obtained in the following cases: the first principal component with the mean air temperature for January-March (GL=86%, $p<0.001$). The second component with the total precipitation for June-August (GL=72%, $p<0.001$), and the third component with the mean temperature for June-August (GL=82%, $p<0.001$) (Fig. 1).

A graphic representation of the dispersion of chronologies representing sequences of radial increments of trees in individual localities in respect to the eigenvectors of the first three principal components are shown in Figure 2. The first principal component (PC1) always integrated the chronologies in each of the three cases. If it is assumed, as indicated by the results mentioned above, that this component is a measure of thermal conditions of winter and early spring

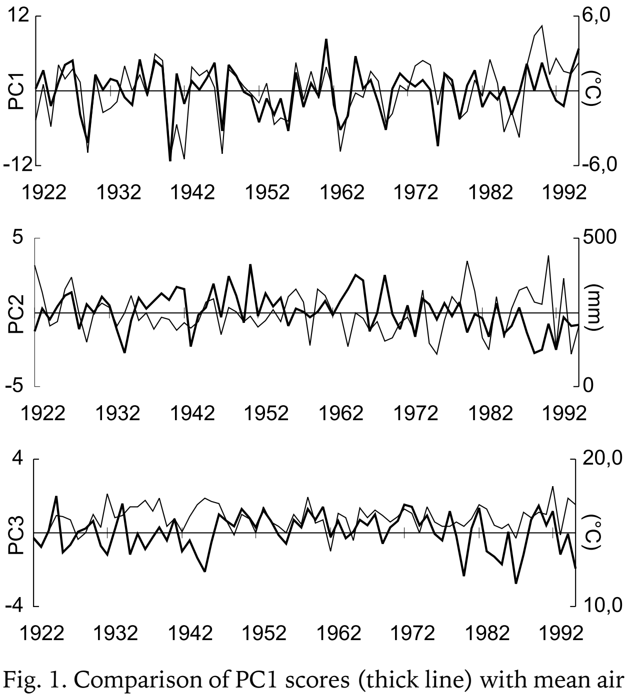

Fig. 1. Comparison of PC1 scores (thick line) with mean air temperature for January-March period (thin line); PC2 scores (thick line) with total precipitation for June–August period (thin line); PC3 scores (thick line) with mean air temperature for June–August period (thin line)

Table 1. Description of forest stands

Forest District Division Compartment	Site code	Altitude (m)	Forest site type	Soil	Species composition	Tree age (years)
Nowa Wieś Purda Leśna 243a	PUR	200	Fresh broadleaved forest	Dystric Cambisol	6 Douglas fir, 3 spruce, 1 pine	100
Orneta Pieniężno 20i	PIE	150	Fresh mixed broadleaved forest	Dystric Cambisol	4 oak, 2 birch, 2 pine, 1 spruce, 1 Douglas fir	80
Orneta Bażyny 462g	BAZ	150	Fresh mixed broadleaved forest	Haplic Arenosol	4 pine, 3 Douglas fir, 2 oak, 1 beech	100
Dobrocin Morąg 240a	DOB	150	Fresh mixed broadleaved forest	Dystric Cambisol	7 oak, 1 pine, 1 birke, 1 Douglas fir	100
Susz Uroczysko 5g	SUS	100	Fresh broadleaved forest	Eutric Cambisol	7 beech, 1oak, 1 spruce, Douglas fir	100
Wejherowo Domatowo 126d	WEJ	100	Fresh broadleaved forest	Dystric Cambisol	6 beech, 2 spruce, 1 oak, 1 pine	100
Tuczno Rzeczyce 101g	TUC	150	Fresh broadleaved forest	Dystric Cambisol	5 pine, 2 birch, 3 Douglas fir	80
Sieradz Reduchów 114f	SIE	160	Fresh coniferous forest	Eutric Cambisol	9 pine, 1Douglas fir	80
Oleśnica Dąbrowa 63j	OLE	150	Fresh broadleaved forest	Albi-Dystric Cambisol	6 pine, 3 Douglas fir, 1beech	100
Namysłów Niwki 105c	NAM	130	Fresh mixed broadleaved forest	Albi-Dystric Cambisol	6 pine, 2 oak, 1 Douglas fir, 1 larch	110
Lubsko Jeziory Dolne 24i	LUB	90	Fresh mixed broadleaved forest	Haplic Luvisol	4 Douglas fir, 4 oak, 2 beech	120
Nowa Sól Mirocin 176h	SOL	95	Fresh mixed broadleaved forest	Albi-Dystric Cambisol	4 oak, 3 Douglas fir, 2 pine, 1 larche	90
Sława Śląska Stare Strącze 331l	SLA	90	Fresh broadleaved forest	Dystric Cambisol	7 Douglas fir, 2 spruce, 1 oak	90
Kościan Olejnica 256h	KOS	80	Fresh mixed broadleaved forest	Dystric Cambisol	7 Douglas, 2 oak, 1 pine	100
Jarocin Cielcza 180a	JAR	90	Fresh mixed broadleaved forest	Dystric Cambisol	9 Douglas fir, 1 oak	100
Miradz Młyny 109a	MIR	105	Fresh mixed broadleaved forest	Eutric Cambisol	4 pine, 3 Douglas fir, 3 oak	115
Łopuchówko Wojnowo 169c	LOP	100	Fresh broadleaved forest	Dystric Cambisol	6 Douglas fir, 4 pine	105
Rzepin Kunowice 190d	RZE	90	Fresh broadleaved forest	Dystric Cambisol	10 Douglas fir	110
Choszczno Ziemomyśl 883g	CHO	100	Fresh mixed broadleaved forest	Albi-Dystric Cambisol	10 Douglas fir	115
Międzyzdroje Warnowo 62f	MIE	10	Fresh mixed broadleaved forest	Haplic Arenosol	10 Douglas fir	115
Sławno Jarosławiec 85c	SLW	120	Fresh mixed broadleaved forest	Dystric Cambisol	10 Douglas fir	115
Lipka Białobłocie 153g	LIP	120	Fresh mixed coniferous forest	Haplic Arenosol	6 Douglas fir, 4 pine	95
Gdańsk Renuszowo 94c	GDA	146	Fresh broadleaved forest	Dystric Cambisol	8 Douglas fir, 1 beech, 1 pine	120
Kwidzyn Gonty 237f	KWI	70	Fresh broadleaved forest	Haplic Luvisol	10 Douglas fir	105
Gryfice Świerzno 645g	GRY	60	Fresh mixed broadleaved forest	Dystric Cambisol	5 Douglas fir, 3 spruce, 1 pine, 1 oak	100
Piaski Sowiny 36c	PIA	200	Fresh broadleaved forest	Luvic Chernozems	5 Douglas fir, 3 oak, 2 ash	105

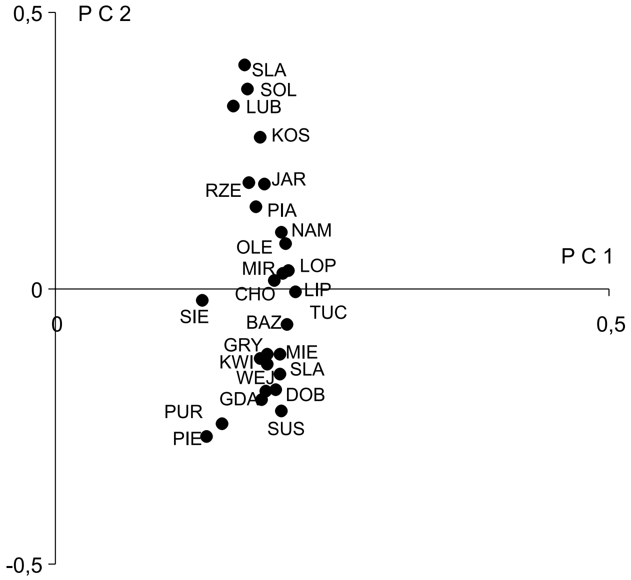

Fig. 2. Comparison of the eigenvectors of the first (PC1) and second (PC2) principal components of the 26 site index chronologies

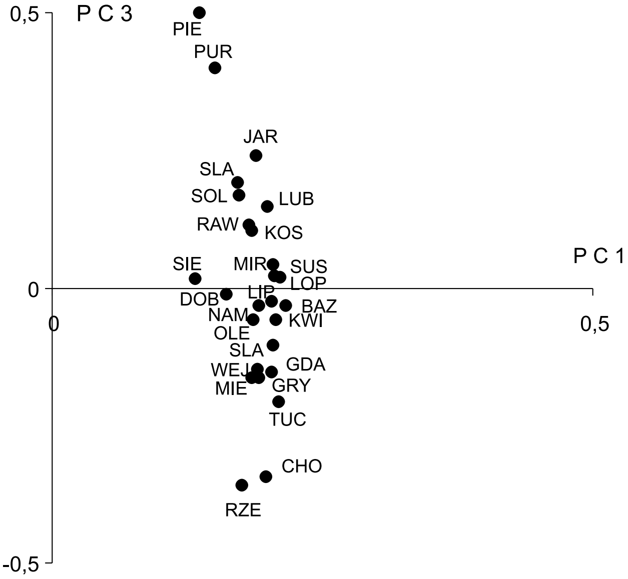

Fig. 3. Comparison of the eigenvectors of the first (PC1) and third (PC3) principal components of the 26 site index chronologies

(January–March), this would mean a homogeneous reaction of trees from all sites to the thermal conditions of this season on the one hand, and a similar spatial rhythm of temperature changes in winter and early spring on the other. The chronologies representing the most eastern localities of Douglas fir, i.e. Warmia, Masuria, and eastern Great Poland (Purda, Pieniężno, Sieradz), differed from the arrangement of sites in respect of the first principal component, as mentioned above (Fig. 2). The thermal regime of winter and early spring in these areas was distinctly more severe than in Pomerania, western Great Poland, and Lower Silesia. For example, in Masuria the mean temperatures of winter months were over 2°C lower, and the mean date of the beginning of early spring was over 10 days later (Niedźwiedź and Limanówka 1992; Kozłowska-Szczęsna 1993). The thermal climate of that season acquired distinct characteristics of the continental climate (Chrzanowski 1991).

The opinion presented above was confirmed by the dispersion of chronologies in respect to eigenvectors of the first (PC1) and third (PC3) principal components (Fig. 3). The third component, which described thermal conditions of summer (June–August), differentiated the chronologies. Separate groups, in respect to loadings of PC3 were formed by the most eastern localities (Pieniężno and Purda), situated in the region with the climate having distinctly continental characteristics, and by the localities of Rzepin and Choszczno, situated in a warm region with the highest number of warm days in a year, the lowest annual amplitudes of air temperature, and the longest growing season (Woś 1999). The remaining localities of Great Poland, Lower Silesia and Pomerania formed a group within which smaller subgroups, determined by a specific thermal climate of summer, may be distinguished (Fig. 3) (Chrzanowski 1991).

Beside air temperature also precipitation of summer (June–August) was a significant factor affecting the variability of radial increment of Douglas fir. This was expressed by the dispersion of chronologies in respect to eigenvectors of the second principal component (PC2). The chronologies in respect of PC2 formed distinctly separated groups (Figs 2, 4) associated with pluvial conditions of areas with Douglas fir localities (Niedźwiedź and Cebulak 1994). In each case, the second as well as the third component differentiated the chronologies (Figs 2, 3, 4). Thus, the separate groups

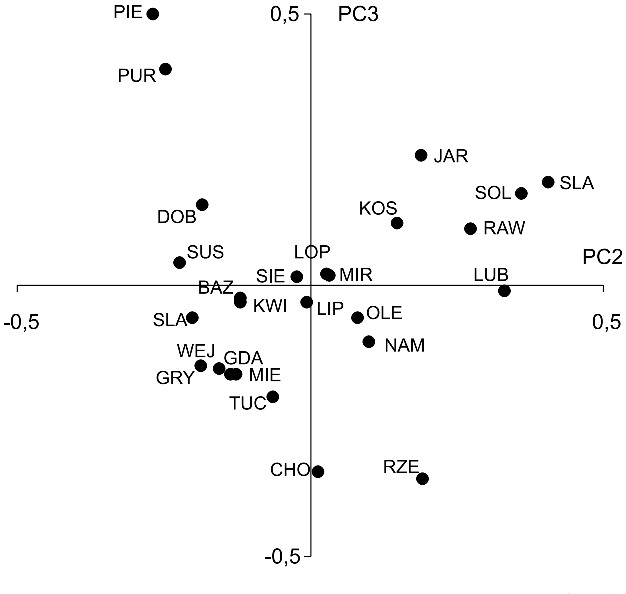

Fig. 4. Comparison of the eigenvectors of the second (PC2) and third (PC3) principal components of the 26 site index chronologies

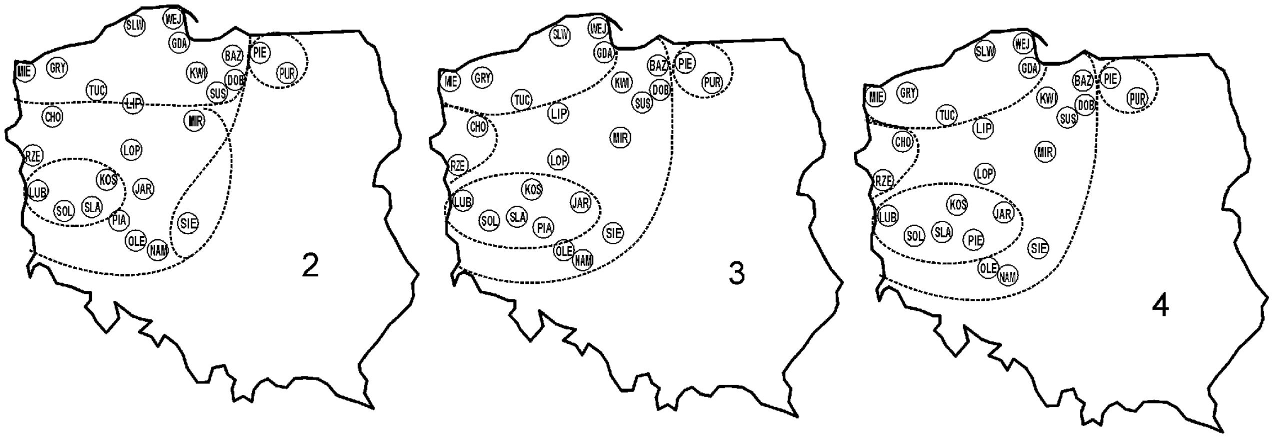

Fig. 5. Map of Poland and investigated sites (dots). The dashed lines separate the dendroclimatic regions of Douglas fir as expressed in Figure 2, 3, 4

of chronologies, associated with the diversification of the thermal and pluvial regime, may be distinguished in the whole area under investigation.

Therefore, on the basis of a principal components analysis, several regions may be distinguished in Poland (Fig. 5), in which Douglas fir trees are characterized by a similar rhythm of radial increments determined by a moderately homogeneous arrangement of thermal conditions of winter and thermal and pluvial conditions of summer. One of them is the region of Pomerania in northern Poland with a mild temperature and a relatively ample precipitation. It includes the following sites: Międzyzdroje, Gryfice, Wejherowo, Gdańsk, Kwidzyń, Bażyny, Dobrocin, and Susz. The second region includes Warmia and Masuria, and it is distinguished by the characteristics of the continental climate with a more severe thermal regime and a relatively high precipitation. It comprises localities of Douglas fir in Pieniężno and Purda Leśna. The third region, the most extensive one, has a mild thermal climate and low precipitation. It includes Douglas fir localities in the Myślibórz and Great Poland lake districts, the eastern part of the Great Poland Lowland, and the Silesian Lowland. The fourth region covers the western part of the Great Poland Lowland with a mild thermal climate and a relatively high precipitation. It includes the localities: Lubsko, Nowa Sól, Rzepin, Sława, Kościan and Jarocin.

Discussion

Douglas fir covers a very extensive territory in its native land between 55° and 19° of the northern latitude. It occurs in British Columbia in Canada, and in Washington, Oregon, California, Idaho, and Montana States in the USA. In this vast area it has become adapted to various site conditions, exhibiting a great plasticity. Among the authors studying the ecology of Douglas-fir prevails the opinion that out of the environmental conditions affecting growth of this tree a considerable role is played by climate (Schober 1963; Tumiłowicz 1967; Chylarecki 1976; Zhang et al. 1999; Kantor et al. 2001; Briffa et al. 2002a, b). It has also been stressed that in most cases precipitation is the most important factor for development and increment of biomass of Douglas fir, not only during the growing season (Biondi 2000), but also in winter, when water is stored in the soil in regions with the arid climate (Fritts 1974; Cleveland 1986).

The Douglas fir introduced to Europe, including Poland, originated from the oceanic as well as continental and mountaneous climates, mainly from British Columbia and Washington State (Berney 1972). The investigations concerning adaptation of Douglas fir to European conditions, carried out hitherto, indicated a very significant effect of climatic conditions on growth and development of this tree species at relatively low soil requirements. Sometimes the effect of climate surpasses the effect of genetic properties (Borowiec 1965; Tumiłowicz 1967; Chylarecki 1976; Kantor et al. 2001).

When young, Douglas fir trees in Europe are susceptible to winter frost, as well as early and late frost. In many experimental areas damage due to frost was considerable, even under conditions of the maritime climate. This susceptibility of Douglas fir to frost decreases with age (Maciejowski 1951; Białobok and Mejnartowicz 1970; Bellon et al. 1977), but then its water requirements increase (Schober 1963; Borowiec 1965; Holubčik 1968; Chylarecki 1976).

In dendroclimatological investigations, where the estimation of the sensitivity of trees to climatic conditions is based on annual increments of vascular tissue, Douglas fir growing in different regions of Poland always exibited a close association between growth reactions and thermal conditions of winter and early spring and in mountains also temperature in summer (Feliksik and Wilczyński 1997, 1998a, b, 2001, 2002, 2003; Cedro 2004). The role of precipitation was always diversified. In mountains a low precipitation in spring limited the activity of the cambium (Feliksik and Wilczyński 2000, 2002), while in lowlands tree-ring widths depended on precipitation in summer (Feliksik and Wilczyński 1997, 1998b, 2003).

The analysis of the spatial diversification of growth reactions of Douglas fir permitted the delineation in Poland of the regions of a dendroclimatic character.

In each region Douglas fir trees were characterized by a similar rhythm of changes in radial increment, determined by thermal conditions of winter and thermo-pluvial conditions of summer, specific for each region. These regions correspond to a considerable degree with areas delineated by Chyralecki (1976), who took the degree of adaptation of Douglas fir to ecological conditions into consideration. The boundaries of these regions also correspond to the ecoclimatic zones distinguished in Poland by Trampler et al. (1990).

Conclusions

The analysis of the spatial diversification of tree-ring widths of Douglas fir permitted distinguishing regions of a dendroclimatic character in western and northern Poland. Within individual regions trees were characterized by a similar rhythm of changes in magnitude of radial increments.

The interregional variation of tree-ring chronologies was mainly determined by air temperature and precipitation in summer (June–August) and by temperature in winter (January–March).

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