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Influence of thermic and pluvial conditions on the radial increments of *Pseudotsuga menziesii* Franco from Western Pomerania, Poland

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Introduction

The Douglas fir (*Pseudotsuga menziesii* Franco) belongs to the most abundant foreign trees planted in Poland. This tree species was introduced to Poland in the 1840s (Szymanowski 1960), and in Western Poland (earlier Prussia) it appeared prior to 1880 (Tumilowicz 1970). The Douglas fir is appreciated for its rapid growth, high productivity (higher than the species naturally occurring in the area), as well as high resistance for pests and diseases (Mejnartowicz 1997).

The first Polish studies on the acclimatisation of Douglas fir in the region date back to the 1920 (works of Tyniecki, Sokołowski, Schappach, see Tumilowicz 1967, Suchocki 1926). These studies focussed on the inventory of existing planted areas, usefulness of seeds from various regions of Northern America to be planted in Poland, and evaluation of the suitability of the timber as a material for sawmills. First attempts to determine the impact of climatic and soil conditions on growth of this tree species were made by Borowiec (1965), Tumilowicz (1967), as well as Birot and Burzynski (1985). These studies demonstrated that the highest negative impact on radial growth of Douglas fir trees was due to low winter temperatures and early-spring frosts. Based on the analysis of the climatic conditions in Poland (the ratio of the total precipitation to the average monthly temperatures), Borowiec (1965) determined the most suitable areas for planting Douglas fir, among others the Pomerania and Baltic Coast regions.

The investigations presented here were based on the fact that various tree species react on changing climatic conditions in different ways. Determination of predominating factors influencing formation of annual growth rings at trees could enable reconstruction of climate beyond the period of instrumental records as well as prediction of dimensions of radial growth in the near future.

Study area

Western Pomerania is located in north-western Poland between Baltic See, Szczecin Bay and Odra Valley. All investigated plots are between 53°57’ to 52°56’ northern latitude and 14°11’ to 15°46’ eastern longitude, at elevations from 5 to 120 m a. s. l. The prevailing tree species are: *Pinus sylvestris* L., *Quercus robur*, *Q. petraea* and *Fagus sylvatica*. The climate in the area (based on stations: Swinoujscie, Resko, Szczecin and Gorzow Wlk.) can be described as transitional between maritime and continental (with Atlantic Ocean and Baltic

See influence). Mean annual temperatures range between 7,8 to 8,5°C and total precipitation between 532 and 683 mm. Maximum mean temperature is 18°C in July and minimum mean temperature may fall down to -9,7°C. Maximum total precipitation 70 to 80 mm are recorded in July, minima of about 30 mm in February and March (Tab. 1).

Material and methods

Field work was carried out in the forest areas directed by the Regional Direction of National Forests in Szczecin and in the Wolin National Park in the years 1998 to 2002. Altogether 16 research sites were established for *Pseudotsuga menziesii* Franco. The plots that met the methodological criteria were selected for further analyses and the choice had been determined by the existence of long-lived trees of the analysed species. Core samples - the basic research materials were taken from 225 trees.

For every sample tree-ring width were measured with 0.01 mm accuracy. Individual dendrograms were dated a chronology was built following the classical methods of dendrochronological crossdating, presented in numerous publications (Schweingruber 1989, Cook and Kairiukstis 1992, Kaennel and Schweingruber 1995). Thereafter, using Arstan (Holmes 1983, 1994), the chronology was indexed eliminating long-term trends (e.g. age trend) and accentuating the year-to-year variability in widths of the tree rings.

The resulting chronology was used as a basis for dendroclimatological analyses such as response function and pointer years. The response function analyses were based on meteorological data (average monthly air temperatures and total monthly rainfall witch was examined for 16-month intervals: from June of the previous year to September of the analysed year in the period of 51 years: 1948-1998) and the indexed values of the tree-ring widths. Except for the current vegetation season, the analyses also included the impact of thermal and pluvial conditions of the preceding summer, autumn, and winter on formation of growth rings at the analysed trees (analysis of periods of 16 months: from July of the previous year to September of the current one (Blasing et al. 1984). The years in which over 90% of the analysed trees exhibited similar growth trends were defined as pointer years. When increments were narrower than the previous year, the pointer years were negative, and contrariwise – positive. Analysis of meteorological conditions and the relationships between the annual increments and climate was carried out for the pointer years, which had been determined with the program TCS (Walanus 2002).

Douglas fir chronologies

16 local chronologies of Douglas fir resulted from various habitats of Western Pomerania. The local chronologies were constructed based on 186 individuals selected from 225 sampled trees (Tab. 2). Average replication of the chronologies was, the highest 15 - for the chronology DG1 from Mysliborz Lakeland - and the least 10 individual trees for the research plots LP2, RY3, WNP4 and WNP5. The longest sequence spans 107-years (chronology WNP2 from a site in the Wolin Island), representing the period 1894-2000, and the shortest 63-years (RY2 from Gryfice Plateau). Average ring width for all local chronologies of Douglas fir (*Pseudotsuga menziesii*) amounts to 3.07 mm, significantly higher than the corresponding

value for Scots pine from Western Pomerania (Cedro 2004). The widest rings (4.04 mm) were noted in trees from site WNP6 (Gryfice Plateau), and the narrowest (1.55 mm) in trees from site DG2 (Mysliborz Lakeland) located southernmost (Tab. 2). No distinct relationship between the average ring widths and the duration of the chronology was observed, which may be due to relatively uniform ages of the analysed trees.

Exeptionally high values of convergence and similarities in local dendrograms for *Pseudotsuga menziesii* indicate predominating influence of environmental factors on the cambial activity and formation of tree rings. The local chronologies established, together with results of convergence, gave rise to construct a standard chronology for Douglas fir from Western Pomerania, labelled PZjedlica. The standard consists of 65 trees (out of 186 investigated trees) displaying the highest similarities of dendrograms (t-values > 6.0, Tab. 3). The regional chronology PZjedlica spans 109 years, between 1894 and 2000.

Results

Analysis of pointer years was carried out for 65 individuals of *Pseudotsuga menziesii* forming the regional chronology (PZjedlica) and for those forming the local chronologies. In case of the regional chronology, 19 pointer years (9 positive and 10 negative, Fig.1) were determined.

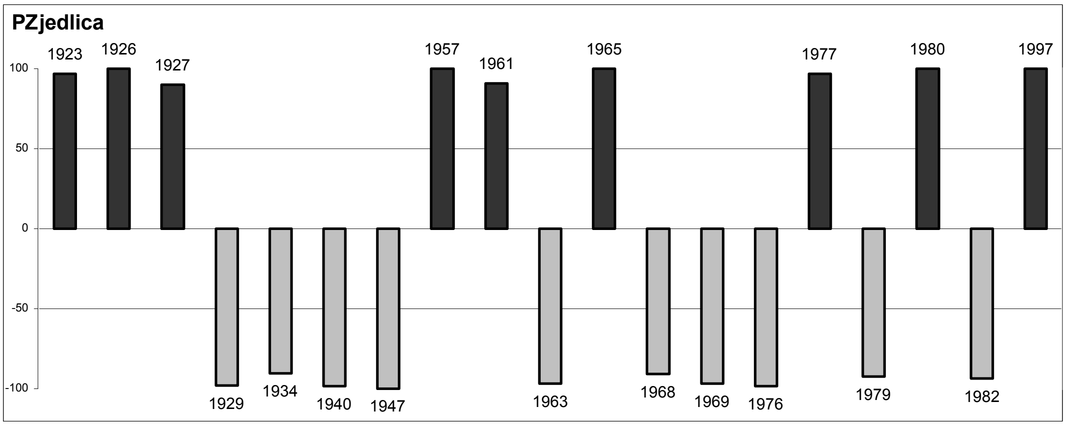

Figure 1: Pointer years determined from growth sequences of regional chronology of Douglas fir for Western Pomerania (PZjedlica).

Negative pointer years occurred in years with frosty and cold winters, with very low values of January and February temperatures. Also temperatures of March were of similar significance for annual growth in the forthcoming vegetation season. Years with cold winters and summer draughts marked deep minima in dendrograms and often continued in the following years. In positive pointer years winter temperatures were predominating; positive temperatures in January and February followed by early spring resulted in formation of wider growth rings. The amount of rainfall in the vegetation season turned out to be of lower importance. In some years (1936, 1948, 1957, 1988, and 1997) decrease of ring widths was noted, in spite of shortage of rainfall in spring and/or summer months.

Table 1: Air temperatures in the period 1948-1998 (in Celsius degree); A – mean monthly temperature, B – minimum monthly temperature, C – maximum monthly temperature. Precipitation in the period 1948-1998 (in mm); A – mean monthly rainfall, B – minimum monthly rainfall, C – maximum monthly rainfall.

TEMPERATURE		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII
Szczecin	A	-0,6	-0,2	3	7,6	12,8	16,2	17,8	17,1	13,6	9	4,2	1	8,5
	B	-8,8	-7,5	-0,9	3,8	10	13,9	15,2	14,7	11,2	6,2	0,2	-6,3	7,1
	C	4,8	6,4	7,5	10,2	16,4	19,3	22,3	20	16,3	11,7	7,4	4,8	10,1
Swinoujscie	A	-0,2	0,1	2,8	6,5	11,3	15,2	17,2	17,1	13,8	9,4	4	1	8,2
	B	-6,2	-7,5	-1,2	3,8	8,9	13,6	14,5	14,7	11,4	6,7	0,8	-5,2	6,9
	C	4,8	6,1	6,2	9,2	13,9	16,8	19,9	20,6	16,6	11,9	7,2	4,7	9,8
Resko	A	-1,1	-0,7	2,3	6,8	12,1	15,4	17	16,6	12,8	8,5	3,7	0,4	7,8
	B	-9,1	-9,6	-1,7	3,6	9,2	13,5	14,2	13,9	10,1	5,3	-0,3	-6,9	6,3
	C	4,3	5,9	6,9	9,8	15,9	17,9	21,4	19,7	15,4	11,2	6,6	4	9,5
Gorzow Wlk.	A	-1,3	-0,6	3	7,8	13,1	16,4	18	17,6	13,6	8,8	3,6	0,3	8,4
	B	-8,7	-9,7	-1,1	4,4	9,8	14,2	14,8	14,7	10,9	5,6	-0,5	-7,2	6,7
	C	4,2	5,5	7,3	11,4	16,5	19,6	22,3	20,9	16,3	11,4	7,1	3,9	9,9
PRECIPITATION		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII
Szczecin	A	35	29	32	37	51	60	69	57	43	37	41	41	532
	B	0	4	5	5	12	8	5	7	4	0	9	6	347
	C	83	76	96	106	128	133	137	141	124	90	104	90	716
Swinoujscie	A	41	30	34	39	47	57	57	56	50	44	47	47	551
	B	0	4	4	4	7	9	0	7	2	0	7	8	377
	C	78	66	94	118	120	146	135	106	158	109	128	123	763
Resko	A	51	39	45	45	54	67	82	72	61	53	54	58	683
	B	1	7	6	7	7	16	9	12	6	0	11	8	441
	C	129	85	105	132	122	195	173	173	150	204	121	130	953
Gorzow Wlk.	A	36	30	32	38	51	64	71	56	42	37	41	43	541
	B	1	4	7	6	11	7	2	9	3	1	6	4	337
	C	116	65	81	88	121	134	195	150	114	114	114	104	752

In most cases, however, tree-ring widths were determined by thermal conditions. Results of dendroclimatical analyses (response function) for Douglas fir are presented in Table 3. The coefficients of linear correlation (k) and multiple regression (r) indicate that radial growth were mostly influenced by temperatures of winter months (January, February) and the beginning of spring (March).

Table 2: Statistical data for local measured and index chronologies of Douglas fir from Western Pomerania

No.	Lab.	No. of	Time	No. of	Mean	Std.	Mean	1st order	Index Chron.			
	code	years	span	samples	RW (mm)	Dev.	sens.	Autocor.	Median	Mean sens.	Std. dev.	1st. order autocor.
1	DG1	78	1922-1999	15	3,87	1,8	0,3	0,67	1,02	0,23	0,2	-0,12
2	DG2	75	1925-1999	11	1,55	0,84	0,28	0,64	1,02	0,21	0,18	0
3	LP2	91	1911-2001	10	1,86	1,04	0,35	0,06	0,99	0,29	0,24	-0,04
4	RES1	68	1934-2001	14	2,48	1,13	0,27	0,64	1,01	0,24	0,22	-0,05
5	RES4	65	1937-2001	11	2,85	1,07	0,27	0,52	1,04	0,24	0,22	0
6	RY2	63	1940-2002	11	3,01	1,16	0,23	0,67	0,97	0,2	0,18	0,09
7	RY3	88	1915-2002	10	2,41	1,03	0,26	0,69	0,99	0,23	0,2	-0,13
8	T1	78	1923-2000	11	3,68	1,62	0,29	0,59	1,01	0,26	0,21	-0,19
9	T2	82	1919-2000	13	3,95	1,75	0,26	0,66	1,03	0,22	0,21	-0,05
10	T5	79	1921-1999	12	2,28	1,13	0,3	0,7	0,97	0,24	0,22	0,02
11	WNP1	98	1903-2000	11	3,68	1,55	0,24	0,72	1	0,21	0,19	0,03
12	WNP2	107	1894-2000	13	3,16	1,2	0,25	0,64	0,99	0,2	0,18	0,01
13	WNP3	101	1900-2000	11	2,82	0,13	0,26	0,71	1	0,22	0,19	-0,07
14	WNP4	89	1912-2000	10	3,92	2,02	0,27	0,73	0,99	0,24	0,2	-0,08
15	WNP5	96	1905-2000	10	3,51	1,52	0,29	0,69	1,02	0,26	0,22	-0,05
16	WNP6	89	1912-2000	13	4,04	2,24	0,3	0,75	1,02	0,26	0,23	-0,07
Mean		84		12	3,07	1,33	0,27	0,63	1	0,23	0,2	-0,04

Table 3: Convergence of Douglas fir local and the regional chronology (PZjedlica) measured with "t" and "Gl" value

Gl/t	DG1	DG2	LP2	RES1	RES4	RY2	RY3	T1	T2	T5	WNP1	WNP2	WNP3	WNP4	WNP5	WNP6	PZjedlica
DG1	X	10,1	7,7	7,6	5,1	5,4	8,6	8,9	8,8	11,7	7,2	10,1	10,6	10	11,4	9	12,6
DG2	77	X	8,7	4,2	3,7	4	6,1	6,1	4,8	7,4	3,7	5,4	5,6	7,3	5,3	4,9	8
LP2	73	70	X	5,6	3,9	4,9	6,8	8,6	8,1	8,4	5,2	9,7	8	5	8,9	7,3	10,9
RES1	67	59	67	X	10,4	7,5	8	7,5	8	7,2	8,1	12,3	9,1	5,7	9,8	7,9	11,5
RES4	68	63	64	72	X	6,4	5,6	6,9	6,7	6,6	5,8	8,1	6	4,4	7,2	5	9,1
RY2	74	70	71	83	80	X	4,2	5,1	5,9	5	4,3	5,1	4,9	5,6	6	4,5	6,3
RY3	72	68	70	69	63	70	X	10	8,7	9,6	8,4	11	11,5	8,7	10	11	10,8
T1	75	70	77	71	73	73	76	X	15,7	15,3	7,3	10,9	10,3	8,9	9	7	15,4
T2	74	74	77	73	76	73	69	82	X	14	9,8	11,9	11,5	7,9	13	9,7	16,5
T5	76	75	78	69	72	71	69	82	85	X	7,1	11,6	10,6	8,9	10,3	9,4	20,2
WNP1	68	64	70	74	66	67	75	73	77	70	X	12,7	11,7	8	12,2	8	7,9
WNP2	71	61	76	83	71	74	74	81	73	74	78	X	16,8	7,9	15,5	11,7	15,2
WNP3	73	65	74	73	64	68	74	74	76	73	78	81	X	9,9	11,6	13,7	12,9
WNP4	75	77	73	72	69	80	76	79	75	75	74	78	77	X	8,6	8,1	9,1
WNP5	73	65	71	77	70	73	68	73	77	75	81	78	75	72	X	11,2	12,7
WNP6	74	70	75	71	66	75	75	73	77	71	73	78	80	80	80	X	12,5
PZjedlica	77	72	86	79	80	80	70	86	84	88	75	84	76	77	81	79	X

Table 3: Response function results for Douglas fir: Pearson correlation coefficient and multiple regression coefficient for air temperature and rainfall. Significant results for α = 0.05: (+) positive, (-) negative.

		CORREATION COEFF. TEMPERATURE																**CORREATION COEFF.** RAINFALL															
No.	Lab. Code	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
1	DG1									+	+					+																	
2	DG2		-		-					+	+		-																				
3	LP2		-							+	+															+					+		
4	RES1	+		-						+			-						+						-		+				+		
5	RES4	+								+			-												-	+							
6	RY2	+			-																				-		+						+
7	RY3			-					+	+	+															+					+		
8	T1									+	+											+				+							
9	T2									+	+		-												-	+							
10	T5									+	+		-													+							
11	WNP1								+	+	+											+				+							
12	WNP2	+								+															-	+							
13	WNP3	+						+		+	+															+							
14	WNP4		-	-						+	+																					-	
15	WNP5			-						+	+							+								+							
16	WNP6									+	+											+			-	+							-

		REGRESSION COEFF. TEMPERATURE																**REGRESSION COEFF.** RAINFALL															
No.	Lab. Code	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
1	DG1		-					+		+			-			+			+		-		+		-	+			+		+		
2	DG2		-		-					+	+	-	-		-	+			+								+					-	
3	LP2		-	-	-					+	+					+										+	+	+	+	+		-	
4	RES1							+		+	+	-	-				-			+					-		+			+	+	-	+
5	RES4	+			-			+		+	+	-	-				-	+				+			-	+	+		+	+	+		+
6	RY2	+	-		-			+	-	+			-	+											-		+					-	+
7	RY3		-	-				+		+	+																				+		
8	T1		-		-					+	+										-	+				+			+				
9	T2				-				+	+	+		-												-	+		+	+	+			
10	T5				-					+	+	-	-				-					+			-	+		+	+	+	+		-
11	WNP1							+	+	+	+		-									+			-	+	+						
12	WNP2	+								+	+			-				+							-	+	+	+					
13	WNP3		-		-				+	+	+									+	-	+				+	+	+				-	
14	WNP4				-					+	+		-						+		-		+			+							
15	WNP5				-				+	+	+		-								-	+				+			+				
16	WNP6				-				+	+	+		-									+			-	+		+					-

In all analysed occurrences of Douglass fir in Western Pomerania have been influenced mostly by the thermal conditions of February. The years with mild winters and early, warm spring have been marked by wider growth rings in the following vegetation season. The response function indicated lower influence of rainfall than of air temperatures. January revealed negative February and March positive relationships. High amounts of total monthly rainfall in February and March are connected with predomination of western circulation pattern in the region. Frequent atmospheric low pressure systems, bringing humid and mild Atlantic air masses, result in an increase of both air temperatures and rainfall, which in turn leads to higher cambial activity in the forthcoming vegetation season. On the other hand, rainfall in summer months of a current growth season seems to have no significant influence on tree growth.

The high values of determination coefficient (r^2 = 63% in average, minimum 50% in the plot WNP4, maximum 75% in the site WNP6) indicate significant influence of the climatic factors on annual growth of Douglas fir in Western Pomerania.

Discussion

Dendroclimatological studies on the Douglas fir in Poland performed by Feliksik and Wilczynski (1997, 1998a, 1998b, 1999, 2001, 2004a, 2004b) revealed similar relations between climatic factors and annual increment as of the Douglass fir from the Western Pomerania; predominating impact of winter thermal conditions, particularly February. Tree growth positively correlates with temperatures of February (Feliksik and Wilczynski 1997, 2004a, 2004b), and of January, February, and March in the vicinity of Bielsko-Biala (Feliksik 1999). Except for the response function analysis these authors also compared average indexed dendrochronological curves of the analysed sites (including the research plot near Gryfice) with average temperatures for the period December-April, and noted almost total convergence of both (Feliksik and Wilczynski 1997, 2004a). Similar results were obtained for the Karkonosze Mts, NE Poland (Feliksik and Wilczynski 1998a, b), as well as for the Silesian Beskid Mts (Feliksik and Wilczynski 2001). In the last region the authors analysed annual growth rings of several species of foreign and native coniferous trees with response functions. Three of the analysed species: *Picea abies* L., *Pseudotsuga menziesii*, and *Chamaecyparis lawsoniana* revealed high sensitivity on the temperatures of winter and early spring (January, February and March), *Larix kaempferi* did not. Douglas fir, similarly to *Picea abies* L. and *Chamaecyparis lawsoniana*, reacted positively on high rainfall in the summer season (June, July).

Dendroclimatological studies on the Douglas fir growing in natural habitats in North America have been led by numerous researchers, which may be related to the wide range of this tree species. The relationships determined between ring width and climatic factors mostly depend on climate and habitat type; for example growth of *Pseudotsuga menziesii* in New Mexico and Colorado (steppe habitats) mostly depends on the amount of rainfall during vegetation season (Cleaveland 1986). In SW Canada the correlation of climatic parameters and ring widths of earlywood, and latewood, based on 40 chronologies for Douglas fir, demonstrated the predominating role of the atmospheric precipitation for tree-ring formation. Development of earlywood depends on the rainfall in the previous summer, while latewood formation depends on the rainfall in June and July of the current vegetation season. Air temperatures are of lesser importance – correlation coefficient values are negative, especially between May and July, when high temperatures enlarge the evapotranspiration and water stress (Watson and Luckman 2002).

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