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TREE RING CHRONOLOGIES OF SCOTS PINE (*PINUS SYLVESTRIS* L.), BLACK PINE (*P. NIGRA* ARNOLD), AND BLACK ALDER (*ALNUS GLUTINOSA* (L.) GAERTN.) FROM THE SŁOWIŃSKI NATIONAL PARK AND NEIGHBOURING FORESTS

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Abstract. Tree ring chronologies of Scots pine (*Pinus sylvestris* L.) and black pine (*P. nigra* Arnold) from the dry coniferous forest and the fresh mixed coniferous forest, as well as black alder (*Alnus glutinosa* (L.) Gaertn.) from the alder swamp forest, in the Słowiński National Park and neighbouring forests (Damnica Forest District) are presented. For both pine species 1940, 1956, 1976, and 1996 were the negative signature years, while 1946, 1957, and 1989 were the positive ones. In black alder the diameter increment depressions occurred in 1997 and 1998. The tree ring width in both pine species was positively correlated with the mean monthly air temperatures in February and March, while there was no univocal precipitation-tree growth relationship found. In some cases, in black pine from the fresh mixed coniferous forest and black alder from the alder swamp forest, the statistically significant coefficients describing the precipitation-increment relationship had negative values. The increment depressions, which occurred in both pine species during 1981--1983, were the result of the nun moth (*Lymantria monacha* L.) outbreak. Black alder was not attacked by this phyllophagous insect. The positive July precipitation-tree growth relationship was found in both pine species during the nun moth outbreak.

Key words: dendrochronology, pine, alder, temperature, precipitation, *Lymantria monacha* outbreak, tree ring

INTRODUCTION AND STUDY AIM

The variation of the tree ring width is decisively affected by climate, because soil conditions change little with time. Temperature, especially during the growing season, insolation, and precipitation are the meteorological elements which in the first place affect the activity of the cambium [Fritts 1976, Bednarz 1992, Zielski and Krąpiec 2004]. Also the occurrence of harmful insects may limit the diameter increment of trees

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[Straw 1996, Podlaski and Wojdan 1993, Zielski and Krąpiec 2004]. Outbreaks of phyllophagous insects frequently occur in the forest. They most often occur in pure and even-aged stands growing on poor sites, especially when precipitation is low [Śliwa 1989]. One of the important forest insect pests is the nun moth (*Lynantria monacha* L.) which in the early 1980s caused enormous damages in forests of the northern and western parts of Poland [Śliwa 1987, 1989].

The aims of this study were to develop tree ring chronologies of Scots pine (*Pinus sylvestris* L.), black pine (*P. nigra* Arnold), and black alder (*Alnus glutinosa* (L.) Gaertn.) from the Słowiński National Park and neighbouring forests of the Damnica Forest District, to determine the climate (mean monthly air temperature and total monthly precipitation) – tree ring width relationship, and to determine the effect of the nun moth feeding on radial increments of trees during the outbreak of this insect pest.

STUDY AREA

Studies were carried out in forests of the Słowiński National Park (N54°43', E17°13') and in stands in a direct neighbourhood of the southern boundary of the Park, belonging to the Damnica Forest District (N54°40', E17°24'; Fig. 1). These forests are situated from several hundred meters to several kilometers away from the Baltic coast at the height of 8 meters above the sea level. According to the division of Poland into natural forest regions this area is situated in the Słowiński Sea Coast Mesoregion, Maritime Belt Province, Baltic Region [Trampler et al. 1990].

Fig. 1. Location of the study area
Rys. 1. Lokalizacja terenu badań

In the Słowiński National Park the pine stands under investigations were growing on the dry coniferous forest site in the phytosociological association *Empetro nigri-Pinetum*, while pine stands investigated in the Damnica Forest District were growing on the fresh mixed coniferous forest site in the association *Querco roboris-Pinetum*. The black alder stands were growing on the alder swamp forest site in the association *Ribeso nigri-Alnetum* [Matuszkiewicz 2001].

Climate

The climate of this area is mild of relatively small annual temperature amplitude. It is cool, moist, and windy. Such climatic features are the result of the nearness of the Baltic Sea. The annual amplitude of mean monthly temperatures (17.9°C) is the smallest in Poland. Winters are mild while summers are relatively cool and short. July and August are the warmest months (16.3°C and 16.2°C respectively), while February is the coldest month (–1.6°C). The duration of summer, as well as winter, is about two months, and thus the remaining seasons are prolonged, especially the autumn. The growing season lasts for about 200 days. It begins in the first decade of April and ends between 5th and 10th November. Amount of precipitation varies in individual years. This is shown by a considerable difference between maximum and minimum total annual precipitation (379 mm) at the mean value of 652 mm. The lowest monthly total precipitation occurs in spring (March-May), and the highest in summer (June-August). Snow occurs during 40 days a year, on the average, and the snow cover lasts for about 50 days [Piotrowska 1997].

MATERIAL AND METHODS

This study concerned trees of Scots pine (*Pinus sylvestris* L.), black pine (*Pinus nigra* Arnold), and black alder (*Alnus glutinosa* (L.) Gaertn.). The sample trees were devoid of external deformations and disease symptoms. According to Kraft's classification the selected trees belonged to dominant and codominant trees. They originated from five populations growing in four different stands. In each population 30 trees were cored. From each tree, using the Pressler's increment borer, two cores were taken at breast height along two radii perpendicular to each other. Tree heights were measured with Sunto hypsometer and breast height diameters with a special tape. Tree characteristics are presented in Table 1.

The increment cores taken were used to determine the tree ring widths. These measurements were done in the laboratory using the measuring set BIOTRONIK BEPD4C exact to 0.01 mm. Dating accuracy was verified using the computer program COFECHA, version 6.06P [Holmes 1986]. During verification the sequences of a strong individual increment pattern, much different from the mean increment curve (standard curve), were rejected. The chronologies (dendroscales) were standardized in order to eliminate individual dissimilarity and a senile trend. For this purpose the program ARSTAN [Cook and Holmes 1986], commonly used in dendrochronological analyses, was applied.

The tree ring width indexes obtained by standardization were used to compute coefficients of Pearson rectilinear correlation. The tree ring widths were correlated with mean monthly temperatures and mean monthly total precipitations. Variables consisted of monthly values of temperature and precipitation from April of the previous year to August of the current year. Correlations were computed for individual years and decades. Computations were completed using the program STATISTICA 6.0.

The climatic data used in this study were obtained from the Łeba meteorological station of the Institute of Meteorology and Water Management (N54°46', E17°34').

Table 1. Characteristics of investigated trees
Tabela 1. Charakterystyka drzew będących obiektami badań

Number of tree Numer drzewa	*Pinus sylvestris* age 95 years – wiek 95 lat BMśw, Nadl. Damnica			*Pinus nigra* age 120 years – wiek 120 lat BMśw, Nadl. Damnica			*Pinus sylvestris* age 115 years – wiek 115 lat Bs, SPN			*Pinus nigra* age 85 years – wiek 85 lat Bs, SPN			*Alnus glutinosa* age 60 years – wiek 60 lat Ol, Nadl. Damnica		
	height wysokość m	$d_{1,3}$	Kraft class klasa Krafta	height wysokość m	$d_{1,3}$	Kraft class klasa Krafta	height wysokość m	$d_{1,3}$	Kraft class klasa Krafta	height wysokość m	$d_{1,3}$	Kraft class klasa Krafta	height wysokość m	$d_{1,3}$	Kraft class klasa Krafta
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	23.25	45.00	II	24.75	35.50	I	11.00	23.50	I	13.70	35.00	II	15.00	24.00	III
2	25.50	42.00	I	23.00	46.00	III	11.40	25.50	I	16.00	41.00	I	17.75	25.50	III
3	28.00	46.00	I	23.00	51.25	III	12.20	25.00	I	13.20	38.00	II	18.50	31.00	II
4	27.50	40.00	I	23.25	41.25	II	14.20	32.50	I	14.20	30.00	II	21.75	29.25	I
5	22.00	38.00	III	24.50	39.75	II	10.50	28.25	I	13.80	34.00	II	22.00	33.75	I
6	24.50	46.25	I	24.50	45.00	II	10.20	31.00	II	14.10	32.50	II	25.25	34.75	I
7	22.25	40.50	III	24.25	43.50	II	12.50	29.75	I	17.50	36.00	I	23.50	42.50	I
8	23.00	40.25	II	25.50	46.00	I	11.80	39.25	I	15.40	38.00	I	23.50	32.25	I
9	22.50	36.00	II	25.25	46.00	I	11.50	39.00	I	17.30	34.00	I	22.50	34.25	I
10	23.50	46.50	III	25.25	44.75	I	13.80	33.75	I	15.70	42.25	I	23.75	30.75	I
11	22.75	45.50	II	25.25	43.50	I	14.50	43.75	I	16.20	44.75	I	24.25	46.75	I
12	23.25	37.00	II	26.25	40.50	I	14.00	39.75	I	19.00	37.25	I	24.00	47.00	I
13	23.75	37.25	II	26.00	47.50	I	12.70	39.00	I	16.00	29.50	I	21.75	33.00	I
14	22.25	35.25	III	28.00	46.50	I	12.50	39.00	I	16.40	31.75	I	23.25	32.25	I
15	22.25	35.00	III	26.00	41.00	I	12.20	42.50	I	16.50	39.25	I	19.00	34.50	II

Table 1 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
16	22.25	36.50	III	27.50	42.00	I	13.50	33.75	I	15.30	37.25	I	21.25	34.25	I
17	23.75	37.00	I	26.25	47.75	I	9.00	26.50	II	11.20	27.00	III	19.50	36.25	II
18	23.00	39.00	II	22.00	52.00	III	9.00	26.50	II	16.50	38.25	I	21.75	37.50	I
19	23.25	40.00	II	24.00	47.00	II	9.20	25.50	II	13.20	37.50	II	20.25	32.25	I
20	22.75	41.50	III	25.25	54.75	I	9.20	27.00	II	14.20	35.25	II	24.00	33.00	I
21	24.25	38.75	I	26.50	48.00	I	9.60	22.50	II	16.40	34.00	I	18.20	28.75	II
22	25.25	43.00	I	27.75	41.00	I	9.50	33.00	II	17.50	36.25	I	19.00	34.75	II
23	25.00	40.50	I	27.25	60.25	I	11.00	31.00	I	16.60	27.00	I	21.00	28.25	I
24	23.25	39.00	II	26.75	54.25	I	11.50	34.00	I	14.40	27.50	II	18.75	28.75	II
25	22.75	38.75	III	25.25	47.75	I	8.50	30.75	III	17.00	35.00	I	21.50	31.75	I
26	28.00	41.50	I	24.00	50.00	II	10.20	30.25	II	16.20	39.00	I	22.25	33.00	I
27	25.00	40.00	I	28.50	40.25	I	9.20	32.50	II	17.00	41.00	I	19.25	44.50	II
28	26.00	41.25	I	25.00	46.25	II	12.20	39.75	I	17.00	35.50	I	24.75	31.75	I
29	23.25	38.75	II	26.25	46.00	I	10.50	32.50	I	16.70	42.00	I	23.50	32.50	I
30	27.00	42.50	I	27.25	45.75	I	12.00	35.75	I	12.80	29.25	III	24.00	37.75	I
Mean Średnia	24.03	40.28		25.48	46.03		11.30	32.43		15.57	35.50		21.49	33.88	

Abbreviations: BMśw – fresh mixed coniferous forest, Bs – dry coniferous forest, Ol – alder forest, Nadl. Damnica – Damnica Forests District, SPN – Słowiński National Park, $d_{1.3}$ – trunk diameter at 1.3 m above soil level (DBH).

Skróty: BMśw – bór mieszany świeży, Bs – bór suchy, Ol – ols, Nadl. Damnica – Nadleśnictwo Damnica, SPN – Słowiński Park Narodowy, $d_{1.3}$ – średnica pnia na wysokości 1,3 m od powierzchni gruntu (pierśnica).

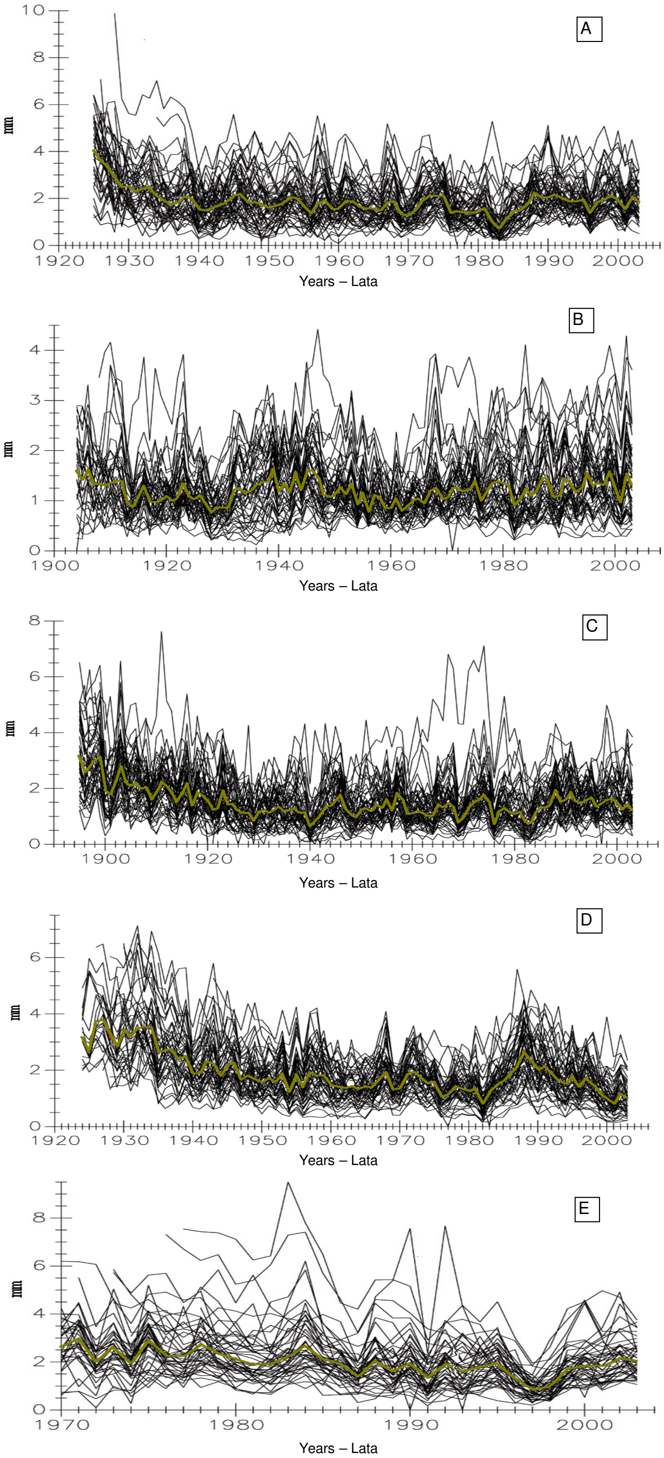

Fig. 2. Actual tree ring chronologies: A – Scots pine from the fresh mixed coniferous forest (Damnica Forest District; 57 sequences) with the mean marked, B – Scots pine from the dry coniferous forest (Słowiński National Park; 54 sequences) with the mean marked, C – black pine from the fresh mixed coniferous forest (Damnica Forest District; 56 sequences) with the mean marked, D – black pine from the dry coniferous forest (Damnica Forest District; 57 sequences) with the mean marked, E – black alder from the alder swamp forest (Damnica Forest District; 47 sequences) with the mean marked

Rys. 2. Rzeczywiste chronologie słojów rocznych: A – sosny zwyczajnej z BMśw (Nadl. Damnica; 57 sekwencji) z zaznaczoną średnią, B – sosny zwyczajnej z Bs (SPN; 54 sekwencji) z zaznaczoną średnią, C – sosny czarnej z BMśw (Nadl. Damnica; 56 sekwencji) z zaznaczoną średnią, D – sosny czarnej z Bs (SPN; 57 sekwencji) z zaznaczoną średnią, E – olszy czarnej z Ol (Nadl. Damnica; 47 sekwencji) z zaznaczoną średnią

RESULTS

Actual and standardized chronologies

The following five actual and standardized chronologies were elaborated: for Scots pine from the fresh mixed coniferous forest from the Damnica Forest District, comprising 79 years; for Scots pine from the dry coniferous forest from the Słowiński National Park, comprising 100 years; for black pine from the fresh mixed coniferous forest from the Damnica Forest District, comprising 109 years; for black pine from the dry coniferous forest from the Słowiński National Park, comprising 80 years; and for black alder from the alder swamp forest from the Damnica Forest District, comprising 34 years (Fig. 2 and 3). All pine chronologies were quite similar (Fig. 2). In the case of Scots pine 1940, 1956, 1976, and 1996 were the years of a deep increment depression fulfilling conditions of so called signature years, while 1946, 1957, and 1989 were the years of increment culmination (Fig. 2 and 3).

In actual chronologies between 1981 and 1983 (period of the nun moth outbreak) there occurred a distinct decrease of the tree ring width of all trees, and during that period in Scots pine growing on the fresh mixed coniferous forest site the increment minimum took place (Fig. 2). Afterwards, smaller or greater increase of the annual ring width was observed in all populations (Fig. 2). This was especially evident in the case of black pine from the dry coniferous forest (Fig. 2 D).

In Scots pine from the dry coniferous forest in the Słowiński National Park increment fluctuations were most distinct. Beginning with the 1930s a systematic increase of annual diameter increments was observed. It lasted for about 17 years, and then in the late 1940s the width of annual rings started to decrease. Beginning with the early 1960s their width started to increase again, and this increasing process is taking place until the present moment (Fig. 2 B).

The deepest increment depression in black alder from the Damnica Forest District occurred in 1997 and 1998. After that period a continuous increase of the tree ring width was observed (Fig. 2 E). Similarly as both pine species the black alder reacted with decrease of diameter increment during the nun moth outbreak, but increment from that period was only slightly lower than its mean value.

The signature years and the decrease of increment during the nun moth outbreak were also distinct on the standardized curves, mainly in the case of populations growing on the fresh mixed coniferous forest site (Fig. 3). In two consecutive years, 1982 and 1983, increment indexes reached values close to the mean for 1984 (Fig. 3 A and C). While in pines growing on the dry coniferous forest site a distinct increment decrease occurred only in 1982. In 1983 the index of the tree ring width reached the value close to the mean (Fig. 3 B and D). In black alder the increment minimum occurred during 1997-1998 (Fig. 3 E).

Temperature and precipitation as meteorological elements shaping the tree ring width

In the investigated stands the relationship between the width of annual rings and the air temperature was similar in all cases, and it was mainly connected with winter temperatures (December-March). However, the influence of the mean temperatures of February

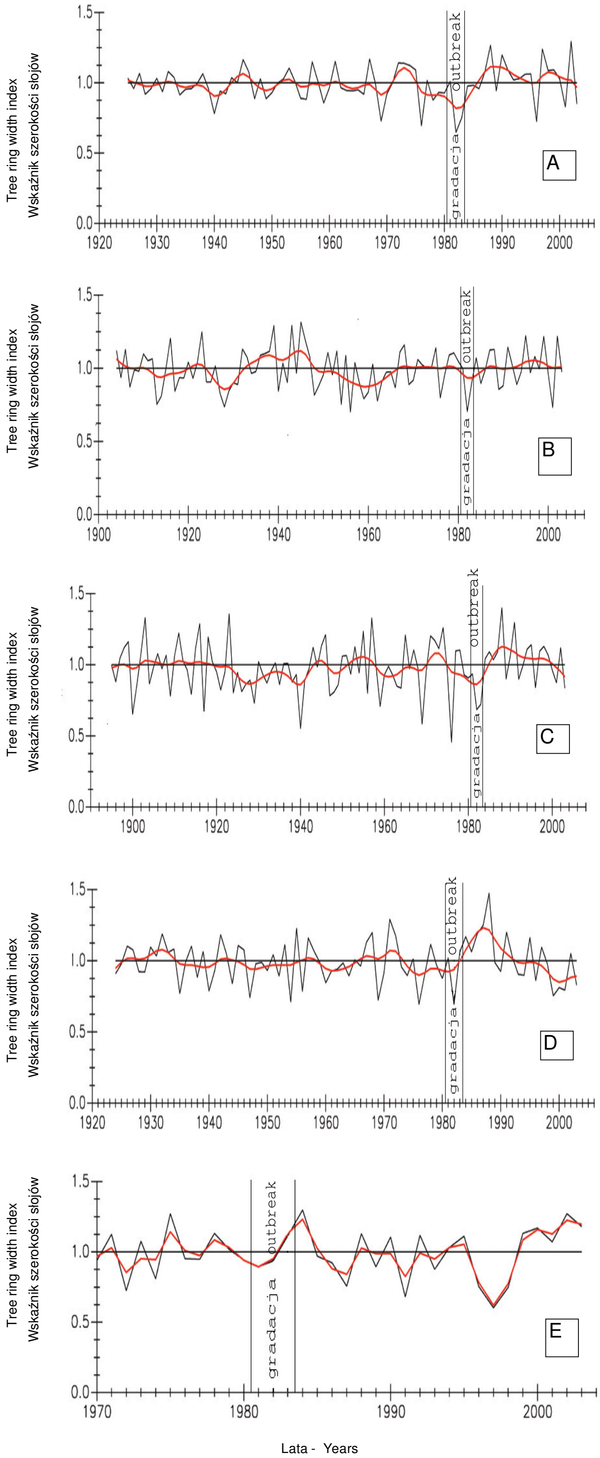

Fig. 3. Standardized and smoothed tree ring chronology of: A – Scots pine from the fresh mixed coniferous forest (Damnica Forest District), B – Scots pine from the dry coniferous forest (Słowiński National Park), C – black pine from the fresh mixed coniferous forest (Damnica Forest District), D – black pine from the dry coniferous forest (Słowiński National Park), E – black alder from the alder swamp forest (Damnica Forest District). Abbreviations as in Tables 1-3

Rys. 3. Standaryzowana i wygładzona chronologia słojów rocznych: A – sosny zwyczajnej z BMśw (Nadl. Damnica), B – sosny zwyczajnej z Bs (SPN), C – sosny czarnej z BMśw (Nadl. Damnica), D – sosny czarnej z Bs (SPN), E – olszy czarnej z Ol (Nadl. Damnica). Skróty jak w tabelach 1-3 and March on the annual wood increment was the strongest one (Table 2). High air temperature in September of the year previous to ring formation limited the diameter increments in Scots pine from the fresh mixed coniferous forest as well as black pine from the fresh mixed coniferous forest and dry coniferous forest. While in black alder the tree ring width was most strongly correlated with temperature of the current year January. The relationships between the mean air temperature of winter months and the width of annual rings were stronger for pines from the fresh mixed coniferous forest than from the dry coniferous forest. In the case of both these forest site types the correlation values obtained for Scots pine were higher than those for black pine (Table 2).

For mean temperatures of February and March values of correlation coefficients were as follows: for Scots pine from the fresh mixed coniferous forest $r = -0.4747$ at $n = 76$ ($p < 0.05$), for Scots pine from the dry coniferous forest $r = 0.3193$ at $n = 77$ ($p < 0.05$), for black pine from the fresh mixed coniferous forest $r = -0.3808$ at $n = 77$ ($p < 0.05$), and for black pine from the dry coniferous forest $r = 0.1871$ at $n = 77$ ($p < 0.05$). All values of correlation coefficients, except the correlation for black pine from the dry coniferous forest, were statistically significant (Fig. 4). In all populations there was a distinct decrease of the tree ring width in 1982, and then, in spite of low January and February temperatures, the ring width increased during subsequent years (1984-1988).

In the case of the monthly total precipitation no definite influence on radial increment of the investigated trees was found. The relationship between the tree ring width and the total precipitation in July occurred only in the decade 1979-1988 in which the nun moth outbreak took place, as well as in some other years (1925, 1955, 1967, and 1972). In these cases the amount of precipitation was closely correlated with the width of annual rings (Table 3). In the case of black pine and black alder rare significant correlations between precipitation and radial increment usually had negative values (Table 3). During complete nun moth defoliation of trees in 1982 and 1983 the total precipitation in July and August was 5 and 12 mm respectively, and it was much smaller than the long-term mean for these months (80 mm each). For these reasons the standardized tree ring chronologies for pines were confronted with the amount of precipitation in July (Fig. 5).

DISCUSSION

The results of this study showed that for Scots and black pines 1940, 1956, 1976, and 1996 were the years of deep growth depressions, while 1946, 1957, and 1989 were the years of diameter increment culminations. These data are in agreement with signature years reported for Scots pine from other regions of Poland [Feliksik et al. 2000]. This indicates a supraregional character of climatic phenomena affecting the formation of annual rings in pines.

It is well known that growth of trees is greatly affected by climatic factors [Bednarz 1992, Bednarz and Niedźwiedź 2006, Karpavichius et al. 1996, Jacoby et al. 1996, Zielski 1997, Wilczyński 1999, Feliksik and Wilczyński 2003, 2004, Zielski and Krąpiec 2004]. The dependence of the tree ring width on temperature and precipitation is not limited to the current season of cambium functioning [Straw 1996, Zielski and Krąpiec 2004]. Proper thermal conditions and water supply during the dormant season also affect

Table 2. Correlation coefficients (r) and significance levels (p) of tree ring widths indices with mean monthly temperatures in the previous year and in the year of ring formation

Tabela 2. Współczynniki korelacji (r) oraz poziomy istotności (p) wskaźników szerokości słojów rocznych ze średnimi miesięcznymi temperaturami powietrza w roku poprzedzającym przyrost i w roku jego tworzenia

	Species Gatunek		Mean monthly temperatures in the year preceding ring formation Średnie miesięczne temperatury roku poprzedzającego przyrost									Mean monthly temperatures in the year of ring formation Średnie miesięczne temperatury w roku formowania przyrostu							
			IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
Chronologie – Chronologies	*Pinus sylvestris* (BMśw)	r	0.0913	0.0080	0.0197	–0.0115	–0.0217	–0.2598	–0.0763	0.0517	0,2717	0.2072	0.4382	0.4031	0.1825	0.0459	0.2409	0.1195	0.2059
		p	0.4330	0.9460	0.8660	0.9210	0.8520	0.0230	0.5130	0.6570	0,0180	0.0720	0.0000	0.0000	0.1150	0.6940	0.0360	0.3040	0.0740
	Pinus sylvestris (Bs)	r	–0.0223	0.0670	0.1333	–0.0476	0.0702	–0.1855	0.0122	0.1205	0,1117	0.0671	0.3247	0.2275	0.2229	–0.0025	0.1890	0.2621	0.3910
		p	0.8470	0.5620	0.2480	0.6810	0.5440	0.1060	0.9160	0.2960	0,3340	0.5620	0.0040	0.0470	0.0510	0.9820	0.1000	0.0210	0.0000
	Pinus nigra (BMśw)	r	–0.0567	0.0223	0.1759	–0.1230	–0.1807	–0.2876	0.0162	–0.0898	0,2747	0.1928	0.4023	0.2484	0.1263	–0.0366	0.0381	–0.0270	0.1575
		p	0.6250	0.8470	0.1260	0.2870	0.1160	0.0110	0.8890	0.4370	0,0160	0.0930	0.0000	0.0290	0.2740	0.7520	0.7420	0.8160	0.1710
	Pinus nigra (Bs)	r	–0.1903	–0.1090	–0.0195	–0.0956	–0.1046	–0.3335	0.0953	0.0804	0,3056	0.0694	0.2452	0.0501	0.1172	0.0885	–0.0690	0.1325	0.2860
		p	0.0970	0.3460	0.8670	0.4080	0.3650	0.0030	0.4100	0.4870	0,0070	0.5480	0.0320	0.6650	0.3100	0.4440	0.5510	0.2510	0.0120
	Alnus glutinosa (Ol)	r	0.1326	–0.1904	–0.2032	0.0262	–0.2359	0.2973	–0.0068	0.0780	0,2874	0.4544	0.1548	0.2249	0.1354	0.3780	0.2274	0.1721	0.1056
		p	0.4770	0.3050	0.2730	0.8890	0.2010	0.1040	0.9710	0.6770	0,1170	0.0100	0.4060	0.2240	0.4680	0.0360	0.2190	0.3550	0.5720

Abbreviations: BMśw – fresh mixed coniferous forest, Bs – dry coniferous forest, Ol – alder forest. Grey coloured coefficients of correlation are statistically significant ($p < 0.05$).

Skróty: BMśw – bór mieszany świeży, Bs – bór suchy, Ol – ols. Szarym kolorem zaznaczono współczynniki istotne statystycznie ($p < 0,05$).

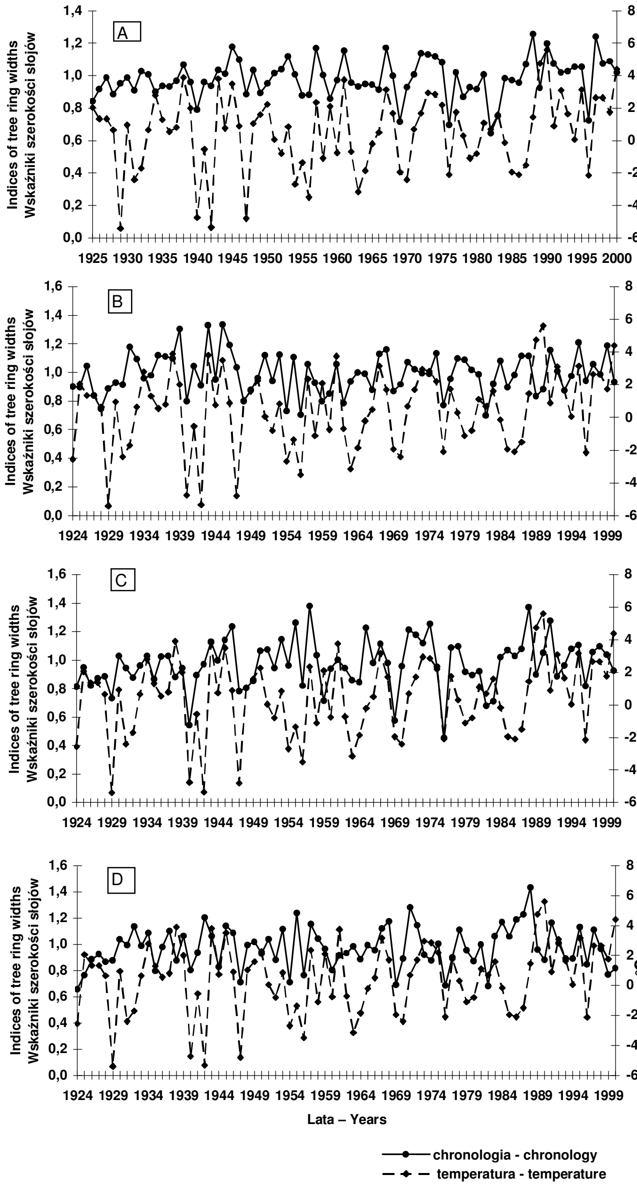

Fig. 4. Comparison of the standardized tree ring chronology of Scots pine and black pine with the mean temperatures of February and March: A – Scots pine (fresh mixed coniferous forest, Damnica Forest District, B – Scots pine (dry coniferous forest, Słowiński National Park), C – black pine (fresh mixed coniferous forest, Damnica Forest District), D – black pine (dry coniferous forest, Słowiński National Park. Abbreviations as in Tables 1-3

Rys. 4. Porównanie standaryzowanych chronologii sosny zwyczajnej i czarnej ze średnią temperaturą powietrza lutego i marca: A – sosna zwyczajna (BMśw, Nadl. Damnica), B – sosna zwyczajna (Bs, SPN), C – sosna czarna (BMśw, Nadl. Damnica), D – sosna czarna (Bs, SPN). Skróty jak w tabelach 1-3

Table 3. Correlation coefficients (r) and significance levels (p) of tree ring widths indices with monthly sums of precipitation in the year preceded ring formation and in the year of ring formation

Tabela 3. Współczynniki korelacji (r) oraz poziomy istotności (p) wskaźników szerokości słojów rocznych z miesięcznymi sumami opadów w roku poprzedzającym przyrost i w roku jego tworzenia

Chronologie – Chronologies	Ten-year Dekada		Sum of monthly percipitation in the year preceded ring formation Miesięczne sumy opadu w roku poprzedzającym przyrost									Sum of monthly percipitation in the year of ring formation Miesięczne sumy opadu w roku formowania przyrostu							
			IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
	1		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Pinus sylvestris (BMśw)	1929-1938	r	0.6513	0.0329	–0.2757	0.0496	–0.1655	0.4140	–0.3946	–0.2450	0.7286	0.2041	–0.2463	–0.1814	0.3353	0.3336	–0.3851	–0.3675	–0.1465
		p	0.0410	0.9280	0.4410	0.8920	0.6480	0.2340	0.2590	0.4950	0.0170	0.5720	0.4930	0.6160	0.3440	0.3460	0.2720	0.2960	0.6860
	1939-1948	r	–0.4022	0.2641	0.4041	–0.5603	–0.2913	0.0708	–0.3599	0.5141	0.1482	0.0837	0.5491	–0.4426	–0.4312	–0.0181	0.5962	–0.2754	0.4431
		p	0.2490	0.4610	0.2470	0.0920	0.4140	0.8460	0.3070	0.1280	0.6830	0.8180	0.1000	0.2000	0.2130	0.9600	0.0690	0.4410	0.2000
	1949-1958	r	0.6240	–0.2130	0.3782	–0.2099	0.4854	–0.0438	0.0466	0.0862	–0.4627	–0.4277	0.0206	–0.0380	–0.4637	0.1552	–0.2001	0.4694	0.3347
		p	0.0540	0.5550	0.2810	0.5610	0.1550	0.9040	0.8980	0.8130	0.1780	0.2180	0.9550	0.9170	0.1770	0.6690	0.5790	0.1710	0.3450
	1959-1968	r	0.2219	–0.3460	0.3737	0.0242	0.4184	–0.2135	–0.1312	–0.0979	–0.2662	0.0518	0.8223	0.2042	–0.4947	0.5555	–0.0064	–0.0769	0.4918
		p	0.5380	0.3270	0.2870	0.9470	0.2290	0.5540	0.7180	0.7880	0.4570	0.8870	0.0040	0.5710	0.1460	0.0950	0.9860	0.8330	0.1490
	1969-1978	r	0.0692	0.1779	0.4824	0.0000	0.2365	0.2328	–0.1202	0.2039	0.3073	–0.6497	0.4214	0.1315	–0.2193	0.4951	0.2617	0.3088	–0.2280
		p	0.8490	0.6230	0.1580	1.0000	0.5110	0.5180	0.7410	0.5720	0.3880	0.0420	0.2250	0.7170	0.5430	0.1460	0.4650	0.3850	0.5260
	1979-1988	r	0.4316	–0.1253	–0.0679	0.1988	0.0339	0.5424	–0.3136	–0.2715	0.0795	0.1146	0.5229	–0.0926	–0.0774	–0.1112	0.0226	0.8499	–0.3573
		p	0.2130	0.7300	0.8520	0.5820	0.9260	0.1050	0.3780	0.4480	0.8270	0.7530	0.1210	0.7990	0.8320	0.7600	0.9510	0.0020	0.3110
	1989-1998	r	–0.5257	0.1554	–0.2655	–0.0238	0.1499	–0.1489	0.3247	–0.0828	0.0162	0.1988	0.5750	0.1586	0.3590	–0.1520	0.1134	–0.3467	–0.2715
		p	0.1190	0.6680	0.4590	0.9480	0.6790	0.6810	0.3600	0.8200	0.9650	0.5820	0.0820	0.6620	0.3080	0.6750	0.7550	0.3260	0.4480
Pinus sylvestris (Bs)	1909-1918	r	–0.0960	0.0043	–0.2798	0.6178	–0.8590	–0.1647	–0.1583	0.4593	0.0545	0.7687	0.3197	–0.4633	–0.3294	0.0580	0.6583	–0.0801	0.1570
		p	0.7920	0.9910	0.4340	0.0570	0.0010	0.6490	0.6620	0.1820	0.8810	0.0090	0.3680	0.1770	0.3530	0.8740	0.0380	0.8260	0.6650
	1919-1928	r	–0.1150	–0.5820	–0.2395	0.3774	0.1159	0.1163	–0.2218	0.1536	0.6263	0.0006	–0.0483	–0.0989	–0.1427	0.5817	0.1929	0.2060	0.1461
		p	0.7520	0.0780	0.5050	0.2820	0.7500	0.7490	0.5380	0.6720	0.0530	0.9990	0.8940	0.7860	0.6940	0.0780	0.5930	0.5680	0.6870
	1929-1938	r	0.3334	–0.2791	–0.2846	0.0207	0.1207	0.3402	0.2001	–0.7690	0.2647	–0.0152	0.0118	0.0215	–0.0786	0.0830	–0.0450	–0.1205	0.2385
		p	0.3470	0.4350	0.4250	0.9550	0.7400	0.3360	0.5790	0.0090	0.4600	0.9670	0.9740	0.9530	0.8290	0.8200	0.9020	0.7400	0.5070

Table 3 – cont.

1				2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Chronologie – Chronologies	*Pinus sylvestris* (Bs)	1939-1948	r	–0.2330	0.4983	0.5710	–0.2638	–0.3023	0.1468	–0.3046	–0.2291	–0.3444	–0.0803	0.4850	–0.3163	0.2146	–0.2358	0.3091	0.2635	0.4318
			p	0.5170	0.1430	0.0850	0.4610	0.3960	0.6860	0.3920	0.5240	0.3300	0.8250	0.1550	0.3730	0.5520	0.5120	0.3850	0.4620	0.2130
		1949-1958	r	0.2941	–0.0162	–0.1604	0.0649	0.1403	0.3258	0.3522	0.7216	–0.0121	–0.5394	–0.1026	0.4756	–0.2834	0.0089	–0.1629	–0.1393	–0.0425
			p	0.4090	0.9650	0.6580	0.8590	0.6990	0.3580	0.3180	0.0180	0.9740	0.1080	0.7780	0.1650	0.4270	0.9800	0.6530	0.7010	0.9070
		1959-1968	r	0.4434	0.0077	0.1021	–0.3677	0.5551	0.3138	–0.1189	0.2984	0.1279	0.1809	0.4237	0.3089	–0.4570	0.3523	–0.1644	–0.2129	–0.0776
			p	0.1990	0.9830	0.7790	0.2960	0.0960	0.3770	0.7440	0.4020	0.7250	0.6170	0.2220	0.3850	0.1840	0.3180	0.6500	0.5550	0.8310
		1969-1978	r	0.1322	–0.2328	0.4263	0.5311	0.0761	0.3794	0.2559	0.2675	0.4841	–0.4035	0.0830	0.0404	–0.4376	0.1272	0.1453	0.2442	0.2336
			p	0.7160	0.5170	0.2190	0.1140	0.8340	0.2800	0.4760	0.4550	0.1560	0.2470	0.8200	0.9120	0.2060	0.7260	0.6890	0.4970	0.5160
		1979-1988	r	0.5397	–0.1467	–0.4999	–0.0153	0.3606	0.5779	–0.5267	–0.4049	0.0073	–0.2419	0.4531	–0.1172	0.0344	–0.1065	–0.0186	0.6768	–0.4975
			p	0.1070	0.6860	0.1410	0.9670	0.3060	0.0800	0.1180	0.2460	0.9840	0.5010	0.1880	0.7470	0.9250	0.7700	0.9590	0.0320	0.1430
		1989-1998	r	–0.4737	0.3415	–0.1094	–0.4726	0.2403	0.5297	0.2241	0.1949	0.2717	0.1951	–0.3821	–0.1529	0.3244	0.3418	0.4096	–0.6250	–0.4516
			p	0.1670	0.3340	0.7630	0.1680	0.5040	0.1150	0.5340	0.5900	0.4480	0.5890	0.2760	0.6730	0.3600	0.3340	0.2400	0.0530	0.1900
	Pinus nigra (BMśw)	1899-1908	r	–0.3060	–0.3210	–0.2745	0.4498	0.2003	0.3555	–0.1502	–0.3821	0.1296	0.4893	0.2998	0.3541	0.4068	0.6285	–0.2178	0.0845	0.5466
			p	0.3900	0.3660	0.4430	0.1920	0.5790	0.3130	0.6790	0.2760	0.7210	0.1510	0.4000	0.3150	0.2430	0.0520	0.5460	0.8170	0.1020
		1909-1918	r	0.2619	0.0107	–0.2726	0.4465	–0.5901	0.0265	–0.1520	0.7176	0.1906	0.4671	0.6770	–0.4919	–0.6148	0.2740	0.7116	–0.3536	0.1924
			p	0.4650	0.9770	0.4460	0.1960	0.0730	0.9420	0.6750	0.0190	0.5980	0.1730	0.0320	0.1490	0.0590	0.4440	0.0210	0.3160	0.5940
		1919-1928	r	–0.0777	–0.4926	–0.0814	0.7757	0.0396	0.0519	–0.3721	0.0276	0.2996	–0.1830	0.3533	–0.1470	–0.4595	0.4686	0.3756	–0.0442	0.4471
			p	0.8310	0.1480	0.8230	0.0080	0.9130	0.8870	0.2900	0.9400	0.4000	0.6130	0.3170	0.6850	0.1820	0.1720	0.2850	0.9040	0.1950
		1929-1938	r	0.2943	0.2860	–0.2646	–0.2738	–0.5286	–0.0186	0.4144	–0.4587	–0.2645	–0.3078	0.3034	0.7021	–0.6573	–0.5684	0.1822	0.4555	0.7102
			p	0.4090	0.4230	0.4600	0.4440	0.1160	0.9590	0.2340	0.1820	0.4600	0.3870	0.3940	0.0240	0.0390	0.0860	0.6140	0.1860	0.0210
		1939-1948	r	–0.4710	0.3315	0.3934	–0.5302	–0.0581	0.1333	–0.3125	0.0684	0.1790	0.1159	0.5873	–0.5226	–0.2773	0.0258	0.7263	–0.1894	0.4138
			p	0.1690	0.3490	0.2610	0.1150	0.8730	0.7140	0.3790	0.8510	0.6210	0.7500	0.0740	0.1210	0.4380	0.9440	0.0170	0.6000	0.2350
		1949-1958	r	0.4832	–0.1447	0.3235	0.2232	0.2315	–0.0664	0.2903	0.3228	0.1255	–0.6235	–0.1005	0.1943	–0.2466	–0.0849	–0.2731	0.1355	0.1834
			p	0.1570	0.6900	0.3620	0.5350	0.5200	0.8550	0.4160	0.3630	0.7300	0.0540	0.7820	0.5910	0.4920	0.8160	0.4450	0.7090	0.6120
		1959-1968	r	0.0151	–0.5421	–0.0034	–0.2051	–0.1863	–0.1232	–0.5646	0.1138	–0.0034	–0.0595	0.6841	0.4126	–0.2533	0.5813	0.1595	0.5138	0.2286
			p	0.9670	0.1050	0.9930	0.5700	0.6060	0.7340	0.0890	0.7540	0.9930	0.8700	0.0290	0.2360	0.4800	0.0780	0.6600	0.1290	0.5250

Table 3 – cont.

1			2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Pinus nigra (BMśw)	1969-1978	r	0.4381	0.0657	0.3542	–0.0598	0.2666	0.3428	–0.2862	0.4284	0.2770	–0.6301	0.4057	0.1458	–0.3306	0.2134	0.4470	0.4835	0.0880
		p	0.2050	0.8570	0.3150	0.8700	0.4570	0.3320	0.4230	0.2170	0.4380	0.0510	0.2450	0.6880	0.3510	0.5540	0.1950	0.1570	0.8090
	1979-1988	r	0.3828	0.0372	–0.0177	0.1241	–0.0048	0.6052	–0.2773	–0.1516	0.0102	0.3145	0.3180	–0.1669	–0.0396	–0.2046	–0.0268	0.8262	–0.3022
		p	0.2750	0.9190	0.9610	0.7330	0.9890	0.0640	0.4380	0.6760	0.9780	0.3760	0.3710	0.6450	0.9130	0.5710	0.9420	0.0030	0.3960
	1989-1998	r	–0.3368	0.0876	–0.5217	–0.1270	0.2528	0.5463	0.2106	0.0668	0.1119	0.4967	0.0171	–0.1081	0.2647	–0.0449	0.7228	–0.4596	–0.2278
		p	0.3410	0.8100	0.1220	0.7270	0.4810	0.1020	0.5590	0.8540	0.7580	0.1440	0.9630	0.7660	0.4600	0.9020	0.0180	0.1810	0.5270
Chronologie – Chronologies *Pinus nigra* (Bs)	1929-1938	r	0.4261	0.1387	–0.3066	–0.6271	–0.4916	0.1841	0.1268	–0.7380	0.0770	–0.4119	–0.0477	0.4807	–0.1848	0.2193	–0.1993	0.5017	0.4904
		p	0.2190	0.7020	0.3890	0.0520	0.1490	0.6110	0.7270	0.0150	0.8320	0.2370	0.8960	0.1600	0.6090	0.5430	0.5810	0.1400	0.1500
	1939-1948	r	0.1102	0.2540	–0.1863	0.0138	–0.4565	–0.2022	0.4335	0.0651	0.2350	0.2404	0.5312	–0.8182	–0.2336	0.3913	0.4574	0.0170	0.2796
		p	0.7620	0.4790	0.6060	0.9700	0.1850	0.5750	0.2110	0.8580	0.5130	0.5030	0.1140	0.0040	0.5160	0.2630	0.1840	0.9630	0.4340
	1949-1958	r	0.1956	–0.0380	–0.1010	0.1243	0.2373	0.2958	0.4454	0.4831	0.0606	–0.6663	0.0616	0.3789	–0.1757	0.0847	–0.1599	0.0304	0.0714
		p	0.5880	0.9170	0.7810	0.7320	0.5090	0.4070	0.1970	0.1570	0.8680	0.0350	0.8660	0.2800	0.6270	0.8160	0.6590	0.9330	0.8450
	1959-1968	r	–0.0743	0.5267	–0.0961	–0.2777	0.4733	0.3746	–0.0646	0.0578	0.3738	0.5600	–0.0475	0.5419	0.0915	0.5246	–0.5488	–0.3522	–0.1978
		p	0.8380	0.1180	0.7920	0.4370	0.1670	0.2860	0.8590	0.8740	0.2870	0.0920	0.8960	0.1060	0.8020	0.1190	0.1000	0.3180	0.5840
	1969-1978	r	0.4263	–0.2813	0.4914	0.3708	0.1336	0.5483	0.0551	0.4277	0.3757	–0.3532	0.0780	0.2386	–0.4199	0.2779	0.5225	0.0658	0.3191
		p	0.2190	0.4310	0.1490	0.2920	0.7130	0.1010	0.8800	0.2180	0.2850	0.3170	0.8300	0.5070	0.2270	0.4370	0.1210	0.8570	0.3690
	1979-1988	r	0.4885	0.0334	0.0320	–0.2992	0.0546	0.4473	–0.3902	–0.3038	0.2652	0.4279	0.5339	0.0659	0.3426	0.2309	–0.1373	0.6220	–0.3660
		p	0.1520	0.9270	0.9300	0.4010	0.8810	0.1950	0.2650	0.3930	0.4590	0.2170	0.1120	0.8560	0.3320	0.5210	0.7050	0.0550	0.2980
	1989-1998	r	–0.3556	0.4241	–0.1221	–0.0535	0.0662	0.4831	0.1570	0.3651	0.1023	–0.0805	–0.1741	–0.0892	0.4090	0.1218	0.4520	–0.5000	–0.6377
		p	0.3130	0.2220	0.7370	0.8830	0.8560	0.1570	0.6650	0.3000	0.7780	0.8250	0.6300	0.8070	0.2410	0.7370	0.1900	0.1410	0.0470
Alnus glutinosa (Ol)	1979-1988	r	0.3045	0.2945	–0.0602	–0.5072	0.1338	0.0490	0.0359	0.0987	–0.3740	0.0567	–0.0773	0.1424	0.1446	0.0554	–0.0343	0.2075	–0.8273
		p	0.3920	0.4090	0.8690	0.1350	0.7120	0.8930	0.9220	0.7860	0.2870	0.8760	0.8320	0.6950	0.6900	0.8790	0.9250	0.5650	0.0030
	1989-1998	r	–0.1520	–0.3687	–0.5464	–0.2151	0.2704	0.4407	–0.6938	0.5250	–0.0043	0.3527	–0.3372	0.4586	–0.4201	–0.6881	0.5245	–0.1304	0.1665
		p	0.6750	0.2940	0.1020	0.5510	0.4500	0.2020	0.0260	0.1190	0.9910	0.3170	0.3410	0.1830	0.2270	0.0280	0.1200	0.7200	0.6460

Abbreviations: BMśw – fresh mixed coniferous forest, Bs – dry coniferous forest, Ol – alder forest. Grey coloured coefficients of correlation statistically significant ($p < 0.05$).
Skróty: BMśw – bór mieszany świeży, Bs – bór suchy, Ol – ols. Szarym kolorem zaznaczono współczynniki istotne statystycznie ($p < 0,05$).

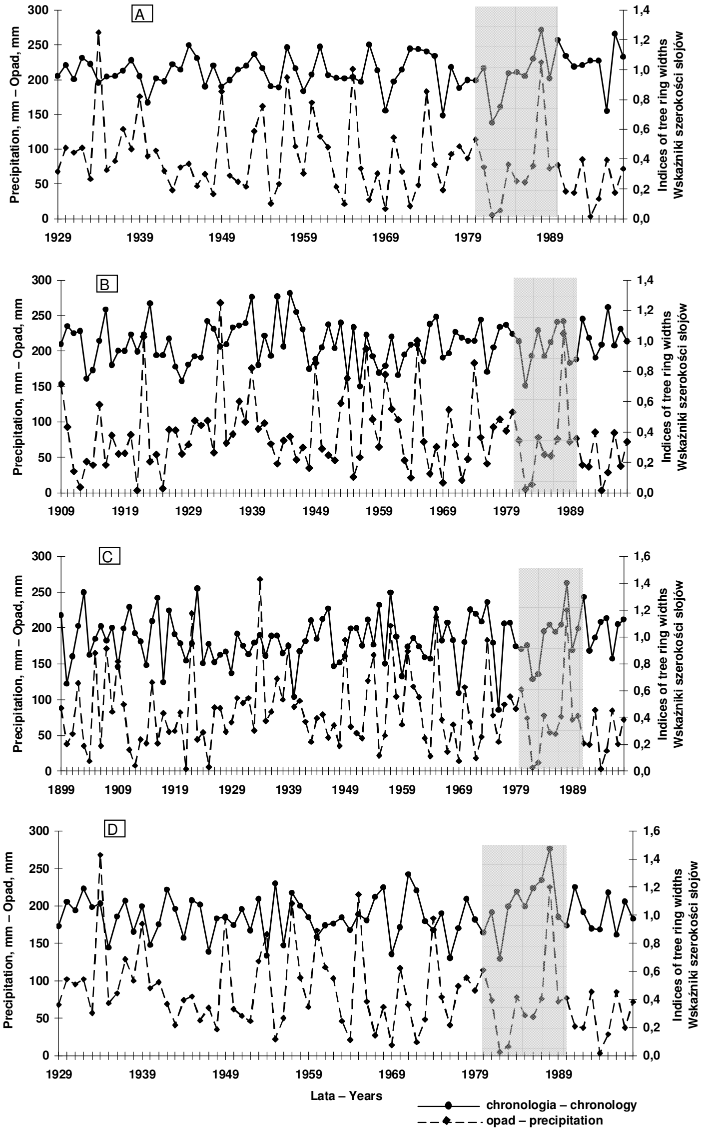

Fig. 5. Comparison of the standardized tree ring chronology of Scots pine and black pine with the total monthly precipitation of July. The decade 1979-1988 in which the nun moth outbreak occurred is marked in grey: A – Scots pine (fresh mixed coniferous forest, Damnica Forest District), B – Scots pine (dry coniferous forest, Słowiński National Park), C – black pine (fresh mixed coniferous forest, Damnica Forest District), D – black pine (dry coniferous forest, Słowiński National Park). Abbreviations as in Tables 1-3

Rys. 5. Porównanie standaryzowanej chronologii sosny zwyczajnej i sosny czarnej z miesięczną sumą opadów lipca. Na szaro zaznaczono dekadę 1979-1988, w której wystąpił masowy pojaw brudnicy mniszki: A – sosna zwyczajna (BMśw, Nadl. Damnica), B – sosna zwyczajna (Bs, SPN), C – sosna czarna (BMśw, Nadl. Damnica), D – sosna czarna (Bs, SPN). Skróty jak w tabelach 1-3 the width of rings produced during the coming growing season. Widths of rings of a given year may be associated even with climatic conditions prevailing during three previous years [Fritts 1976].

The relationships mentioned above were observed when ring widths of the investigated trees were confronted with climatic conditions prevailing during the year previous to ring formation.

The air temperature and atmospheric precipitation of some months may be closely correlated with width of annual rings [Bednarz 1992, Bednarz and Niedźwiedź 2006, Yasue et al. 1997, Zielski 1996, Feliksik et al. 2000, Zielski and Koprowski 2001, Chojnacka-Ożga 2002, Feliksik and Wilczyński 2003, 2004, Zielski and Krąpiec 2004].

Similarly as it has been found in this study also other authors concluded that low air temperatures in late winter and early spring, especially in February and March, have a negative effect on diameter growth of pines [Zielski 1996, Feliksik et al. 2000, Zielski and Krąpiec 2004]. Besides, in our study all pine trees showed the negative correlation with temperature of the previous year September. The diameter increments in black alder were significantly correlated with temperature of the current year January. It was also found that there was a more distinct relationship between the diameter increment of pines growing on a more fertile site of the fresh mixed coniferous forest and the winter air temperatures. The correlation coefficients for Scots pine growing on the dry coniferous forest site were lower, and the significant correlations did not concern September and December. For black pine from the dry coniferous forest the correlation coefficients obtained were lower and did not occur in the case of March temperature (Table 2). Probably this was connected with greater tolerance to environmental stresses of populations growing on poor sites.

The atmospheric precipitation affects the width of annual rings of pines [Straw 1996, Zielski 1996, Feliksik et al. 2000, Zielski and Krąpiec 2004]. In the study concerning the influence of climatic elements on growth of Scots pine on the Baltic coast, including the Słowiński National Park, Zielski [1996] as well as Zielski and Krąpiec [2004] found significant correlation between the tree ring width and the precipitation of summer months in 30 samples. This was not confirmed by the results of our study in spite of a considerable size of the sample (77 trees) and taking into account two quite different forest sites (dry coniferous forest and fresh mixed coniferous forest). Only in the decade 1979-1988 when the nun moth outbreak occurred there was a significant correlation between diameter increment and precipitation in July (sample = 10). At that time, during the period of a complete defoliation of trees in 1982 and 1983, the total July precipitation was 5 and 12 mm respectively, while a long-term average for this area is 80 mm. Thus, feeding of the nun moth occurred during very dry years. The occurrence of dry years probably favours the outbreaks of phyllophagous insects [Śliwa 1989].

On the basis of analyses carried out during our study it may be concluded that there is no explicit answer to the question what role is played by atmospheric precipitation in the process of formation of tree annual rings in the investigated pine populations growing in the Słowiński National Park and the Damnica Forest District. The similar conclusion was drawn by Straw [1996] for Scots pine in Scotland and Zielski [1966, after von Lührte] for Scots pine growing in the vicinity of Berlin.

A lack, or rare occurrence, of significant correlation between the tree ring width and the precipitation in the case of trees growing on the sea coast may be caused by the permanent accessibility of ground water to tree roots. The investigated stands were growing only 3-8 meters above the sea level. In the case of black pine as well as black alder only few correlations between the tree ring width and the total precipitation in individual months were statistically significant, and they were negative correlations only. It may be supposed that fluctuations of the water table resulting from atmospheric precipitation may disturb tree growth through periodic flooding of roots. Black alder as well as Scots and black pines have deep root systems. For example in Scots pine growing on fresh sandy soils the roots may be 6-7 meters long [Jaworski 2004]. Also the forest site type is of importance. Zielski and Krąpiec [2004] found that on sites favourable for tree growth the climatic elements may not limit the diameter growth every year but only during some extreme years. These authors are of the opinion that investigations on the climate-tree growth relationships using statistical methods may not bring correct results in the case of trees growing under various site conditions.

CONCLUSIONS

1. This study confirmed the positive effect of high air temperature of winter months (December, February, and March) and the negative effect of air temperature of the previous year September on diameter growth of Scots pine (*Pinus sylvestris* L.) and black pine (*P. nigra* Arnold) in the Słowiński National Park and the Damnica Forest District (Baltic coast). Growth responses to temperature of winter months and the previous year September were similar in both these pine species.

2. Pine populations growing on more fertile sites of the fresh mixed coniferous forest showed a closer positive relationship between the tree ring width and the air temperature of winter months than it was the case with populations growing on poor sites of the dry coniferous forest.

3. Black alder (*Alnus glutinosa* (L.) Gaertn.) showed the positive significant relationship between width of annual rings and the temperatures of the current year January and May.

4. Tree ring widths of pines and black alder were not significantly correlated with the total monthly precipitation of the previous, nor of the current year.

5. The depressions in diameter increment between 1981 and 1983 were caused in both pine species by feeding of the nun moth (*Lymantria monacha* L.).

6. The analyses of the tree ring width of black alder for the period 1981-1983 did not show the increment regress. This showed a lack of intensive feeding of the nun moth on this tree species.

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CHRONOLOGIE SŁOJÓW ROCZNYCH SOSNY ZWYCZAJNEJ (*PINUS SYLVESTRIS* L.), SOSNY CZARNEJ (*P. NIGRA* ARNOLD) ORAZ OLSZY CZARNEJ (*ALNUS GLUTINOSA* (L.) GAERTN.) ZE SŁOWIŃSKIEGO PARKU NARODOWEGO I LASÓW PRZYLEGŁYCH

Streszczenie. Opracowano chronologie słojów rocznych sosny zwyczajnej (*Pinus sylvestris* L.) i czarnej (*P. nigra* Arnold) z siedliska boru suchego oraz boru mieszanego świeżego, a także olszy czarnej (*Alnus glutinosa* (L.) Gaertn.) z olsu w Słowińskim Parku Narodowym i lasach przyległych (Nadl. Damnica). Latami wskaźnikowymi negatywnymi dla sosen były: 1940, 1956, 1976 i 1996 r., a pozytywnymi 1946, 1957 i 1989 r. U olszy czarnej depresje przyrostowe wystąpiły w latach 1997 i 1998. Szerokości słojów rocznych obu gatunków sosen korelowały pozytywnie ze średnią miesięczną temperaturą powietrza w lutym i marcu, a w wypadku opadów nie stwierdzono jednoznacznego związku przyrost/opad. W kilku przypadkach istotne statystycznie współczynniki opisujące związek przyrostu z opadem przyjmowały wartości ujemne u sosny czarnej z siedliska boru mieszanego świeżego oraz u olszy czarnej z olsu. Depresje przyrostowe występujące u obu gatunków sosen w latach 1981-1983 były następstwem gradacji brudnicy mniszki (*Lymantria monacha* L.), natomiast olsza czarna nie była obiektem żerowania foliofaga. W okresie gradacji u obu gatunków sosny zanotowano istotny pozytywny związek przyrost/opad miesiąca lipca.

Słowa kluczowe: dendrochronologia, sosna, olsza, temperatura, opady, gradacja brudnicy mniszki

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