Dendrochronology of Scots pine (*Pinus sylvestris* L.) in the mountains of Poland

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ABSTRACT: In the area of southern Poland 33 pine stands growing at the altitudes from 350 to 1,200 m above sea level in the Carpathian and Sudeten Mountains were selected as the object of studies. Thirty-three site chronologies of tree-rings, representing each site were constructed. A decrease in the similarity of dendrochronological signal chronologies occurred with the growing distance between the sites. Correlation and convergence analysis and the Principal Components Analysis permitted the differentiation of two chronology groups: the Western (Sudeten) and the Eastern (Carpathian) ones. On the basis of the site chronologies regional chronologies for the Carpathian and Sudeten Mts. were constructed. The investigated pines from the two regions manifested great sensitivity to winter frost and in summer to the deficiency of heat and water. The chronologies were strongly integrated by the pattern of air temperatures, being differentiated by the pluvial conditions.

Keywords: Scots pine; dendrochronology; dendroclimatology

The width of tree-rings changes from year to year supplying valuable information concerning the history of tree growth. The obtained data evidence the effect of various factors on the process of plant growth. In the course of research the records are usually limited to agents significantly affecting the life processes of the investigated organisms. In natural conditions of forest life elements of the habitat exert a complex effect on the organisms. Relations between them, however, make it difficult to examine them.

The climatic factor is the reason of the annual variation in the width of tree-rings while the remaining factors of a different character disturb the climatic signal contained in the chronologies of the radial increments of trees. Moreover, the tree-rings – climate associations are dynamic phenomena, which depend on the character of factors limiting the growth of plants and on the varied sensitivity of individuals to them.

The subject of the present work was the similarity of the annual rhythm of changes in the width of rings of the pines growing in the regions of the Carpathian and Sudeten Mts. The sensitivity of trees to the meteorological conditions in the mountains was also investigated.

MATERIAL AND METHODS

The pine (*Pinus sylvestris* L.) is classified as the species of moderately cool continental climate. In Poland it grows from the Baltic Sea to the Tatra Mts., where it reaches the altitude of about 1,500 m above sea level (BORATYŃSKI 1993). In the mountains of southern Poland numerous pine stands of local provenance are encountered though they grow there outside the limit of the compact distribution range of the species.

The area of Poland is characterized by the climate of transitory character with the confronting continental air masses from the East and marine ones from Western Europe. The Sudeten Mts. situated further to the west manifest many traits of the marine climate. There the annual total precipitation is much higher and its distribution throughout the year is more uniform. In the Carpathians the summer is slightly warmer while the winters are decisively more severe (Fig. 1).

The investigation was conducted on 33 selected sites. They were located in single-species or mixed pine stands at age over 80. In the Carpathian region 28 and Sudeten 5 sites were established (Fig. 1). They represented habitats of the foothills and of the lower tree line, lying in the belt between 350 and 1,200 m above sea level (Table 1).

On each site covering the area of a few to tens of the stand ares 20 predominant trees with properly developed crowns, without any signs of disease or damage were selected. Two core samples were taken from the trunk using the Pressler accretion borer at the height of 1.3 m above the soil. An increment meter was used in measuring annual

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Table 1. Description of the investigated sites and of the statistics of tree-ring and index chronologies

Site No.	Site name	Region	Latitude N	Longitude E	Elevation (m)	Site types	Tree-ring chronologies				Index chronologies			
							Mean growth	Mean sensitivity	V (%)	Autocor. 1 ord	Mean index	Mean sensitivity	V (%)	Autocor. 1 ord
1	Arlamow	Carpathian	49°35′	22 °37′	550	MBF	2.33	0.12	43	0.87	1.00	0.14	12	–0.01
2	Czulnia		49°29′	22 °20′	350	UBF	1.58	0.13	48	0.92	1.00	0.15	14	0.03
3	Czarne		49°18′	22 °15′	700	MMBF	0.89	0.15	21	0.63	1.01	0.17	16	0.09
4	Malinki		49°31′	22 °18′	350	UBF	1.81	0.14	23	0.74	1.00	0.19	14	–0.20
5	Krempna		49°32′	21°26′	550	MBF	1.63	0.15	33	0.86	1.00	0.17	16	0.15
6	Kotan		49°33′	21°33′	550	MBF	0.22	0.12	49	0.91	1.01	0.15	15	0.14
7	Swiatkowa		49°36′	21°25′	550	MBF	2.15	0.13	39	0.89	1.00	0.16	13	–0.01
8	Brunary		49°32′	21°00′	500	MBF	2.64	0.12	46	0.89	1.00	0.15	13	0.02
9	Magura		49°34′	21°09′	500	MBF	1.33	0.14	26	0.80	1.01	0.15	14	0.14
10	Wysowa		49°35′	21°11′	500	MBF	1.07	0.16	27	0.71	1.00	0.17	16	0.05
11	Jazowsko		49°35′	20°30′	500	MBF	1.69	0.13	23	0.72	1.00	0.16	14	–0.08
12	Chelmiec		49°38′	20°37′	450	MBF	1.50	0.16	24	0.65	1.01	0.20	17	–0.11
13	Lipnica		49°43′	20°52′	500	MBF	1.61	0.14	26	0.77	1.00	0.18	15	–0.08
14	Szczawiczne		49°24′	21°01′	650	MMBF	1.46	0.13	20	0.68	1.01	0.16	14	–0.03
15	Tartak		49°22′	20°58′	650	MBF	2.55	0.11	45	0.90	1.00	0.15	12	–0.13
16	Majdan		49°27′	20°42′	450	MBF	1.12	0.19	37	0.84	1.00	0.21	17	–0.04
17	Klodne		49°29′	20°20′	800	MBF	1.28	0.15	26	0.73	0.99	0.18	16	0.07
18	Zielone		49°25′	20°19′	550	MBF	2.55	0.10	42	0.94	1.01	0.13	11	–0.17
19	Macelowa		49°22′	20°15′	550	MBF	1.38	0.14	21	0.60	1.02	0.16	15	0.02
20	Koryciska		49°15′	19°51′	1,200	MCF	1.39	0.12	19	0.71	1.01	0.15	12	–0.08
21	Skalka		49°17′	20°09′	1,100	MCF	0.82	0.15	23	0.64	1.01	0.16	14	0.00
22	Kostrza		49°40′	20°18′	450	MMBF	2.13	0.13	55	0.91	1.02	0.13	13	–0.01
23	Bor		49°25′	20°03′	600	BMG	1.20	0.11	29	0.85	1.00	0.14	13	–0.03
24	Rabka		49°38′	19°58′	500	MBF	2.76	0.13	61	0.93	1.01	0.15	13	–0.05
25	Toporzysko		49°30′	19°50′	600	MBF	1.47	0.13	20	0.67	1.01	0.15	13	0.04
26	Stryszawa		49°42′	19°26′	600	MBF	0.38	0.14	36	0.88	1.03	0.15	16	0.13
27	Slemien		49°43′	19°23′	600	MBF	1.23	0.12	27	0.84	1.00	0.12	12	0.13
28	Okrajnik		49°41′	19°23′	550	MMBF	1.22	0.11	30	0.89	1.01	0.12	11	–0.06

Site No.	Site name	Region	Latitude N	Longitude E	Elevation (m)	Site types	Tree-ring chronologies: Mean growth	Mean sensitivity	*V* (%)	Autocor. 1 ord	Index chronologies: Mean index	Mean sensitivity	*V* (%)	Autocor. 1 ord
29	Godzisz	Sudeten	50°49′	15°48′	500	MMBF	0.82	0.17	18	0.35	1.00	0.18	16	0.03
30	Podgorzyn		50°50′	15°42′	450	MMBF	0.97	0.17	21	0.46	1.00	0.19	16	–0.01
31	Wyszki		50°15′	16°35′	450	MBF	1.03	0.15	26	0.75	1.01	0.18	17	0.11
32	Zlelazno		50°23′	16°43′	450	MBF	0.99	0.19	33	0.76	1.01	0.21	20	0.07
33	Wambierzyce		50°29′	16°23′	500	MMBF	0.84	0.17	25	0.67	1.02	0.20	18	0.11

MBF – mountain broadleaved forest, MMBF – mountain mixed broadleaved forest, MCF – mountain coniferous forest, UBF – upland broadleaved forest, *V* – coefficient of variability, Autocor. 1 ord – autocorrelation of the 1st order

tree-rings exact to 0.01 mm. The correctness of measurements, the time synchronization of the dendroscales (time series of the width of rings in the core increment) and the degree of their homogeneity were tested using the COFECHA program (HOLMES 1986).

The calculation of actual chronologies of tree-rings widths for each site and their indexation (the tree-rings series being standardized and autoregressively transformed) were carried out using the ASTRAN program (COOK, HOLMES 1986). The chronology stresses the traits characteristic of the dendroscales (tree-rings series) of individual trees included in its composition. At the same time it weakens the individual variability associated with the effect of poorer environmental factors. On the other hand the aim of the indexation was to manifest the climatic signal contained in the chronologies. The period 1921–1990 was analyzed. The actual and indexed chronologies were characterized, their basic statistics being given in Table 1.

In order to determine the degree of similarity of the chronologies the calculation concerned the nonparametric percentage of agreement (%GL) (ECKSTEIN, BAUCH 1969) between the actual chronologies and the coefficients of linear correlation (*k*) between the indexed chronologies. For the separation of homogeneous groups of pine stands Principal Components Analysis (PCA) (HOLMES 1986) was carried out for 33 indexed chronologies.

In estimating the climate – increment associations the linear correlation method and the multifactor regression method – "response function" (FRITTS 1976) were used. The climatic data i.e. monthly air temperatures and monthly total precipitation were derived from the Carpathian and Sudeten meteorological stations of the Institute of Meteorology and Hydrology (Fig. 1).

RESULTS

At each site the dendroscales (tree-rings series) of trees were highly and statistically significantly ($P \leq 0.01$) correlated, showing a high similarity of their increment responses and indirectly manifesting their adaptability to the site conditions (ERMICH et al. 1976).

The pattern and statistics of the actual chronologies show that in the tree populations investigated the occurring numerous individual traits are associated with their age, the history of the stand, and the trophy of the habitat (Fig. 2, Table 1).

The mean ring widths of the individual actual chronologies were characterized by the great variation (the range of 0.21–2.76 mm). This also concerned the coefficients of variability (V) of average increments (the range of 17–61%). Also the coefficients of autocorrelation of the 1st order varied at a fairly high level (in the range of 0.35–0.94) and the mean sensitivities from 0.11 to 0.19 (Table 1). In spite of the great variability of the analyzed traits the actual chronologies were characterized by a high conformity in the direction of the annual variation of tree-rings widths (Fig. 2). The conformity was observed in the

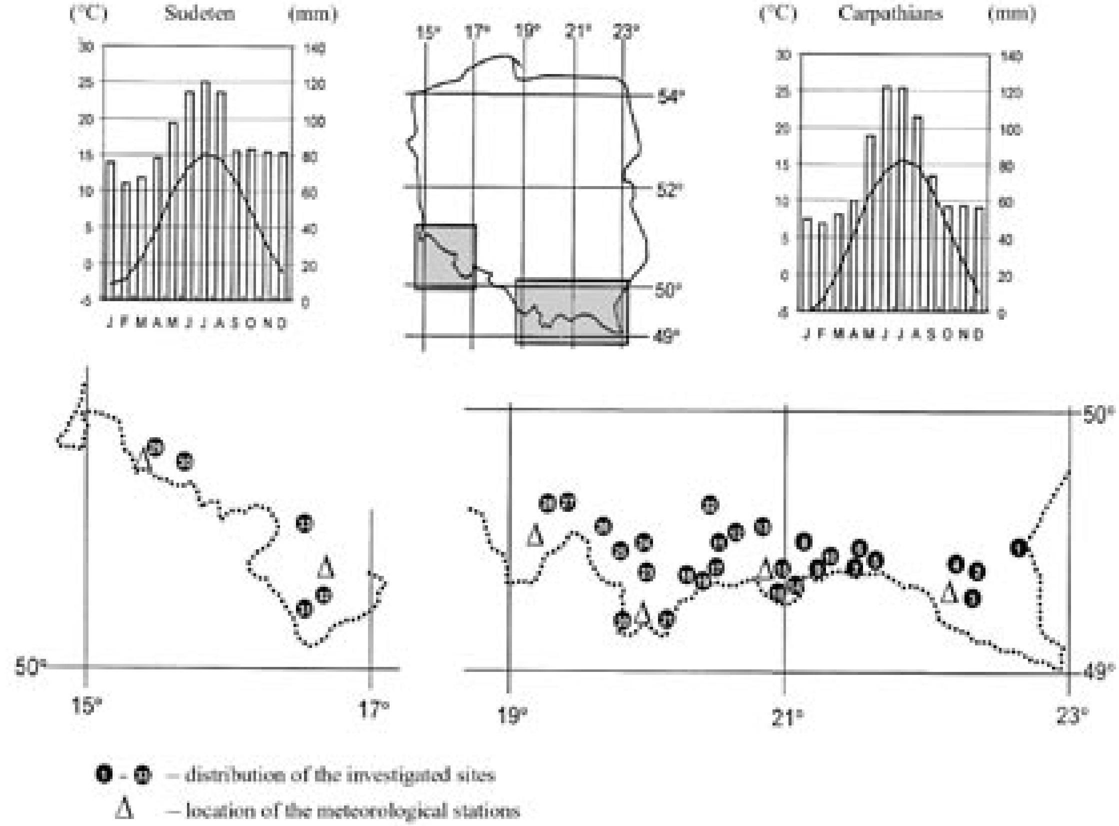

Fig. 1. Map of the investigated sites and meteorological stations in the area covered by the studies; climatic diagrams of the Sudeten and Carpathian Mts.

pattern of chronologies and in the values of the nonparametric percentage of agreement (%GL) (Fig. 3).

The high conformity of the dendroscales and chronologies shows the occurrence of an over-regional factor, whose dominating and at the same time identical impact on the activity of cambium was noted in the trees from all the investigated sites.

The standardized chronologies have a uniform mean value of increment indices equal to one. The coefficients of variability of the mean indices of the individual chronologies are fairly low (the range of 11–20%). A similar observation was made in the case of autocorrelation indices (the range from 0.14 to –0.20), while the mean sensitivities of these chronologies slightly (by about

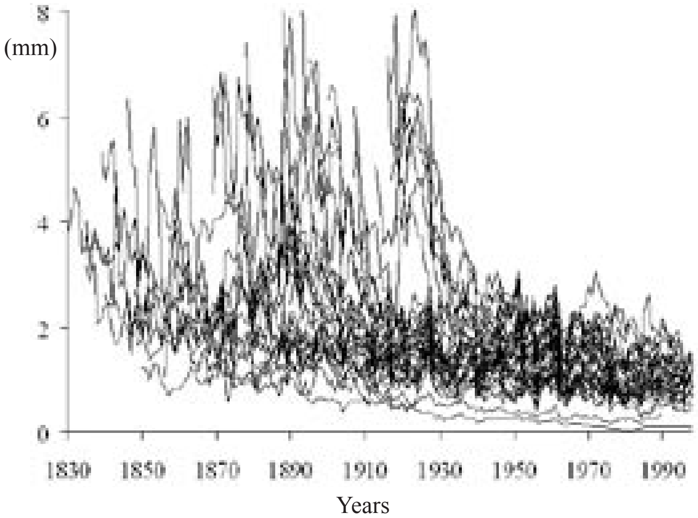

Fig. 2. Site tree-ring chronologies of the ring widths

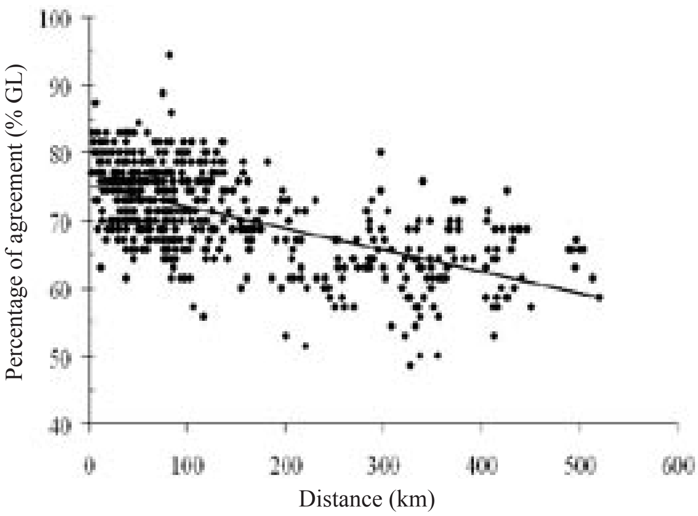

Fig. 3. Dependence between the value of the nonparametric percentage of agreement (%GL) between the chronologies and the distance between the sites. The GL value = 65% for the significance level ($P \leq 0.01$)

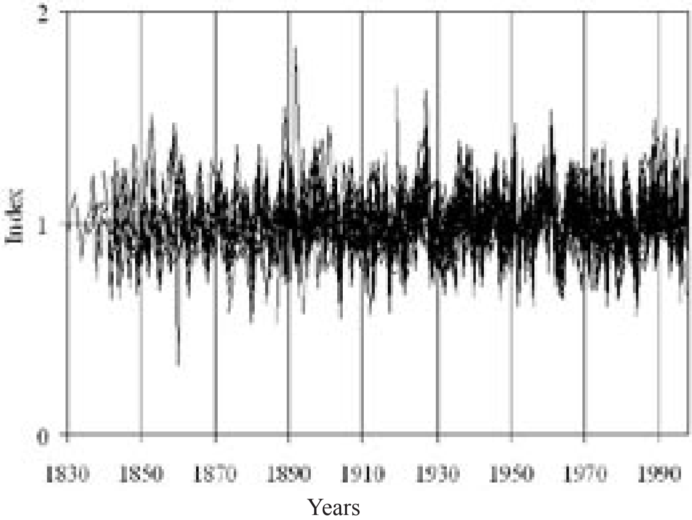

Fig. 4. Site index chronologies of the ring widths

10%) increased in relation to the sensitivities of the actual chronologies (the range of 0.12–0.21) (Table 1). The standardized chronologies became more stable after the trends and long-term fluctuations were eliminated from them, the annual variability of tree-rings (the climatic signal) being stressed thereby. They are also characterized by a high mutual conformity in the annual changes of the value of increment indices (Fig. 4).

The correlation coefficients (*k*) and the nonparametric percentage of agreement (%GL) calculated between the chronologies show the greater similarity the nearer were the sites located. Though it was observed sometimes that

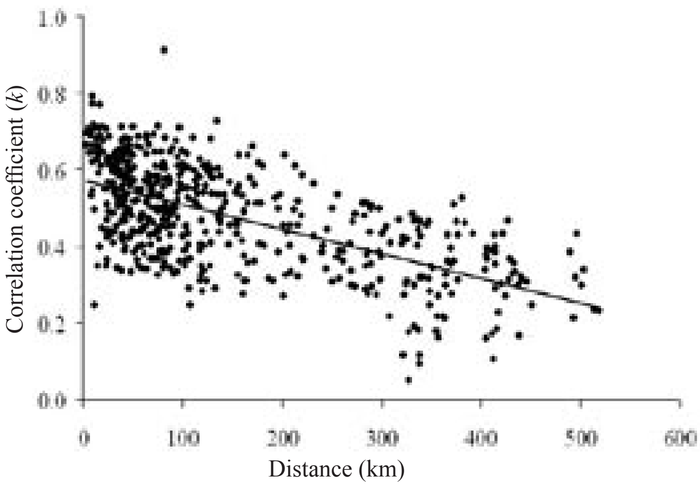

Fig. 5. Dependence between the value of the correlation coefficient (*k*) between the chronologies and the distance between the sites. The value of $k = 0.3017$ for the significance level ($P \leq 0.01$)

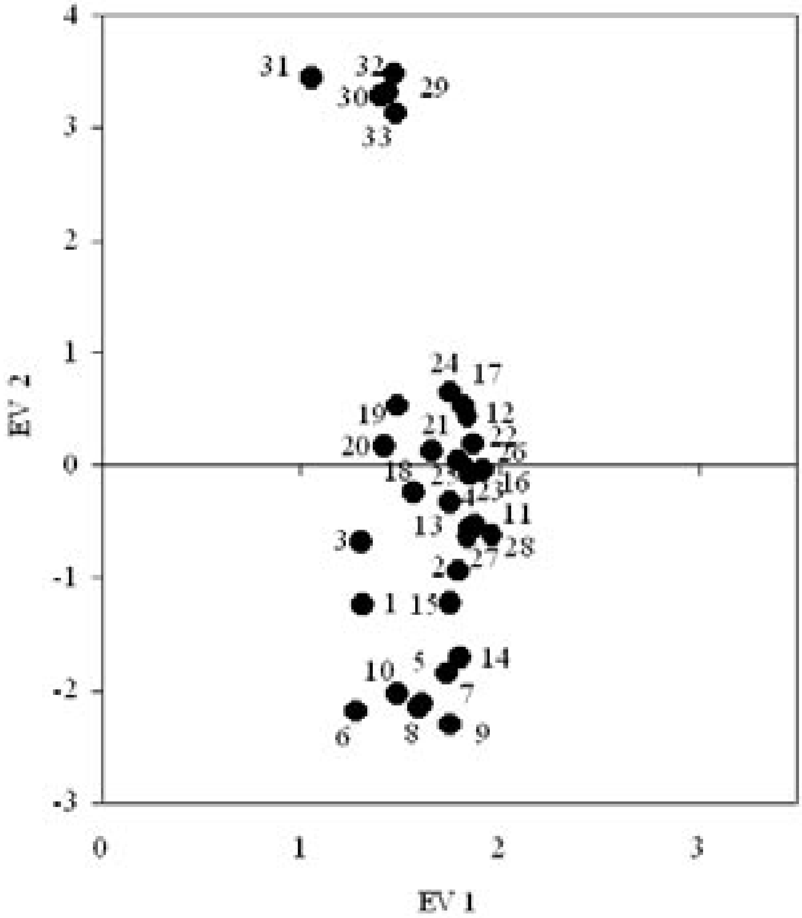

Fig. 6. Scattering of the value of the first and second eigenvector in Principal Components Analysis (PCA) for 33 indexed chronologies

the sites lying at a distance of even more than 500 km showed a highly significant statistical ($P \leq 0.01$) similarity (Figs. 3 and 5).

On the basis of the value of nonparametric percentage of agreement (%GL) and correlation coefficients (*k*) between the site chronologies and also of the results of PCA for indexed chronologies two groups of sites were segregated (Fig. 6). PCA showed that the first vector described the common variability of all 33 standardized chronologies in 50%. At the same time it integrated the investigated chronologies. The other vector only described 8% of the total variability of the chronologies and with respect to its value the chronologies were segregated into two distinct groups. The first group included 5 chronologies from the Sudeten Mts. and the other 28 chronologies from the Carpathians (Fig. 6).

Fig. 7. Regional tree-ring chronologies for the Carpathian Mts. (heavy line) and Sudeten Mts. (light line)

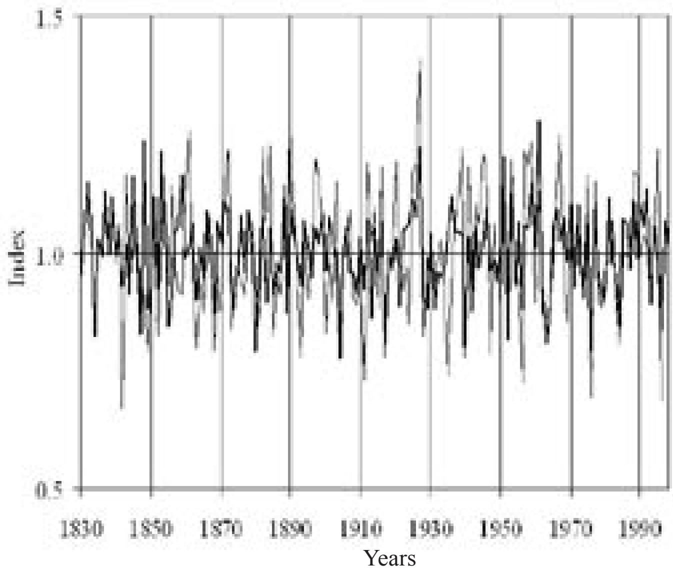

Fig. 8. Regional indexed chronologies for the Carpathian Mts. (heavy line) and Sudeten Mts. (light line)

The distribution of the investigated chronologies is associated with the latitude. This statement varies from the results of similar studies conducted on pine in the territory of Spain. There the factor differentiating the variability of pine chronologies were the moisture conditions connected with the elevation of pine sites above sea level (RICHTER et al. 1991).

In a further stage of the study on the basis of the local chronologies two regional tree-rings chronologies and also index regional chronologies were constructed for the Carpathian and Sudeten Mts. The pine chronology for the Carpathian Mts. included 168 years (from 1830 to 1998) and for Sudeten 161 years (from 1835 to 1996) (Figs. 7 and 8).

Both regional tree-rings chronologies show a very distinct similarity. The calculated the nonparametric percentage of agreement (%GL) between them was 76.7% ($P \leq 0.01$) for the period 1837–1996. Similarly the coefficient of linear correlation (k) calculated for the regional standardized chronologies was high, amounting to 0.58 ($P \leq 0.01$).

It was found on the basis of linear correlation and multiple regression analysis (response function) that the warm and wet vegetation period (April–August) preceded by the warm autumn and winter (October–March) beneficially affected the radial increment of Carpathian pines (Fig. 9). In the Sudeten Mts. dry and cool summer (June–August) and severe winter (January–March) limited the activity of pine cambium there (Fig. 10). In both regions dry September of the current vegetation period favourably affected the prolongation of cambium activity in the trees (Figs. 9 and 10). Thus, the thermic-pluvial conditions prevailing not only in the vegetation period but also in months preceding it have a modelling effect on the activity of cambium expressed by the width of three-rings developed by the pines. It should be stressed that in pine active cambium divisions occur also in September.

The meteorological conditions of the individual years (1921–1990) were confronted with the respective values of main components calculated in PCA. On this basis it was determined that the factor described by the first vector was the thermal air condition integrat-

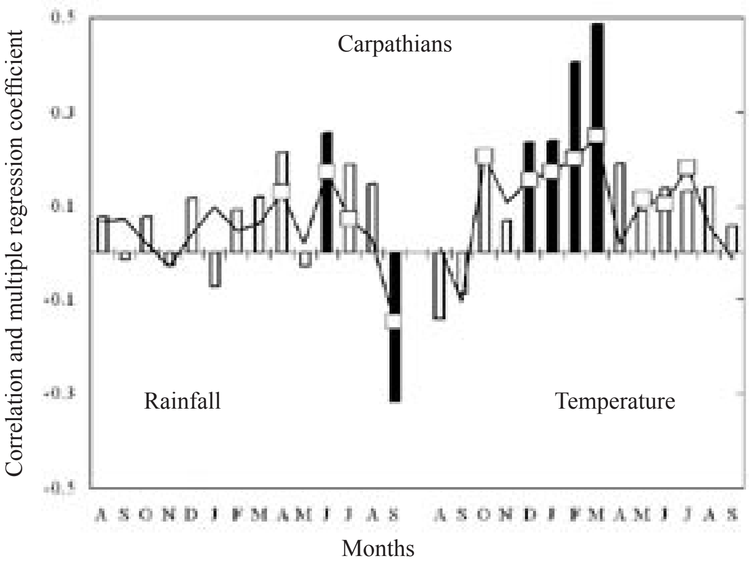

Fig. 9. Response function (line) and correlation function (bars) for Carpathian's pines for the months from August (A) of the year preceding the increment to September (S) of the current vegetation period. Black bars and white squares – values significant for the level ($P \leq 0.01$)

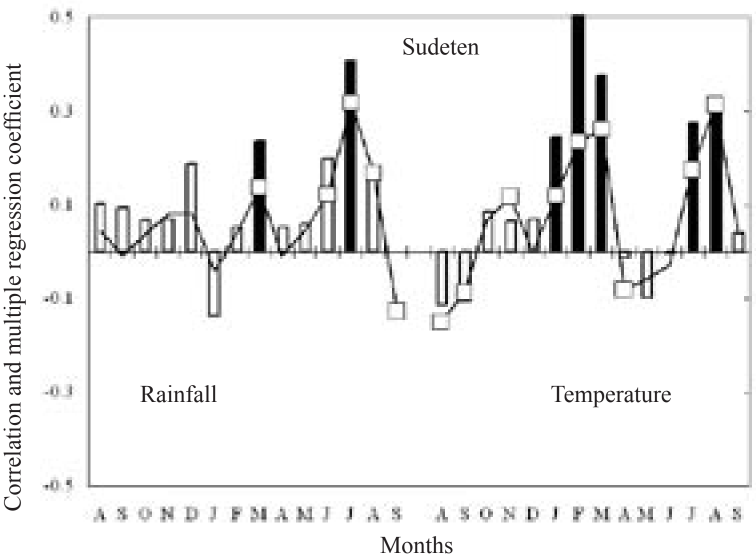

Fig. 10. Response function (line) and correlation function (bars) for Sudeten's pines for the months from August (A) of the year preceding the increment to September (S) of the current vegetation period. Black bars and white squares – values significant for the level ($P \leq 0.01$)

ing the chronologies investigated. This meteorological element has the strongest impact on cambium activity in pine, being also stable on fairly large areas. The element differentiating the chronologies and described by the second vector was the atmospheric precipitation. The pluvial factor is usually more territorially varied than the temperature and in wet mountainous regions (Fig. 1) affects the increment in a less measure than the thermal air conditions.

CONCLUSIONS

The elaborated tree-rings chronologies permitted the determination of tree sensitivity to the meteorological conditions in a given region. Also they can be used in various dendroclimatological studies.

The similarity in the rhythm of changes in the width of tree-rings depends on the distance between the investigated stands. The more distant they are, the lower is the similarity. In the present study it was frequently maintained at a high, statistically significant level ($P \leq 0.01$) even in the case of distance exceeding 500 km.

The pines growing in wet and cool areas of the Carpathian and Sudeten Mts. are sensitive to similar elements of the climate. Their radial increment is chiefly limited by severe winters and dry or cool summer.

The separated two groups of site chronologies are to a greater degree associated with the latitude than with altitude above sea level. Atmospheric precipitation was the element differentiating the investigated chronologies while the thermal air conditions played the integrating role, strongly and similarly modelling their variability.

SUMMARY

The work concerned the problem of similarity in the rhythm of changes in the tree-rings width of pine (*Pinus sylvestris* L.) growing in the area of the Sudeten and Carpathian Mts. in southern Poland (Fig. 1). The investigation covered 33 pine stands lying between 350–1,200 m above sea level (Table 1). Site chronologies of the annual wood increment were constructed for the all investigated stands (Figs. 2 and 4) and two regional's chronologies (Figs. 7 and 8).

The decreasing similarity of the dendrochronological signal chronologies was recorded with the growing distance between the sites. Though in many cases a high similarity of the chronologies was found even with the distance exceeding 500 km (Figs. 3 and 5). Analysis of the linear correlation, nonparametric percentage of agreement, and Principal Components Analysis permitted the segregation of two groups of the chronologies: the western and the eastern ones (Fig. 6). The first group was composed of the chronologies of Sudeten pines and the other of Carpathian chronologies. The division was of geographical character (along a parallel of latitude). The thermal factor integrated the chronologies while the pluvial conditions differentiated them, this being reflected in the varied increment response of pines in the two regions.

It was determined on the basis of correlation analysis and response function that mild winter and of warm and wet vegetation period favourably affected the width of tree-rings of the investigated pines. Also dry and sunny weather in September prolonged the vegetation, beneficially influencing the radial increment (Figs. 9 and 10).

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Dendrochronologie borovice lesní (*Pinus sylvestris* L.) v polských horách

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ABSTRAKT: Dendrochronologická šetření byla provedena ve 33 borových porostech lokalizovaných 350–1 200 m nad mořem v jižním Polsku, v horách Sudetské a Karpatské soustavy. Z výsledků letokruhových analýz byly sestaveny časové řady reprezentující vybrané porosty. Z jejich porovnání je zřejmý pokles podobnosti řad se vzrůstající vzdáleností lokalit. Na základě statistického zpracování získaných dat (analýzy hlavních komponentů, výpočty korelací a konvergencí) byl prokázán rozdíl mezi dvěma skupinami dendrochronologických řad – západní (Sudetská pohoří) a východní (Karpatská pohoří). Pro obě tyto oblasti pak byly sestaveny reprezentativní dendrochronologické řady. Výsledky šetření prokázaly vysokou citlivost sledovaných borových porostů k zimním mrazům a nedostatku tepla a vláhy v létě. Závislost výsledků letokruhových analýz a teploty byla výrazně ovlivněna dešťovými srážkami.

Klíčová slova: borovice lesní; dendrochronologie; dendroklimatologie

Práce se zabývá problémem podobnosti změn tloušťky letokruhů borovice lesní (*Pinus sylvestris* L.), rostoucí v oblasti sudetských a karpatských pohoří v jižním Polsku (obr. 1). Výzkumná šetření byla provedena ve 33 borových porostech v nadmořských výškách 350–1 200 m (tab. 1). Pro všechny vybrané lokality byly sestaveny reprezentativní letokruhové řady (obr. 2 a 4) a rovněž tak i pro obě zájmové oblasti (Sudety a Karpaty, obr. 7 a 8).

Z výsledků je zřejmý pokles podobnosti letokruhových řad se vzrůstající vzdáleností lokalit, i když v některých případech je podobnost řad zřejmá i při vzdálenosti nad 500 km (obr. 3 a 5). Lineární korelace, neparametrické testy shody a analýza hlavních faktorů prokázaly odlišnost dvou skupin letokruhových řad – západní a východní (obr. 6). První skupina je v sudetských a druhá v karpatských pohořích. Rozdělení dendrochronologických řad má geografický ráz podle zeměpisné délky. Teplotní faktor má spojující charakter, srážkový faktor charakter rozdělující. Oba odrážejí rozdílné přírůsty borovic ve dvou zmíněných geografických regionech.

Na základě výsledků korelační analýzy bylo konstatováno, že mírné zimy, teplá a vlhká vegetační období příznivě ovlivňují tloušťku letokruhů sledovaných borovic. Rovněž suché a teplé počasí v září prodlužuje vegetační dobu a příznivě se projevuje na radiálním růstu borovice lesní (obr. 9 a 10).

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