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DEPENDENCE OF SCOTS PINE TREE-RINGS ON CLIMATIC CONDITIONS IN SOUTHERN POLAND (CARPATIAN MTS.)

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ABSTRACT

The aim of the study was to evaluate the effect of air temperatures and atmospheric precipitation on the tree-ring width of Scots pine (Pinus sylvestris L.) growing in Western Carpathian Mts. In 29 pine stands growing between 400 and 700 m above sea level ring samples were taken from 580 trees. The samples were used for measurements of the annual growth rings (dendro-scales). The regional chronology of ring width were calculated as an average from all the 580 dendro-scales. The analysed period was 1900-1998. On the basis of analysis of the response function significant ($P \leq 0.05$) positive relations were found between the width of tree-rings and average temperatures of October of the preceding year and months of the winter (January, February, and March) and summer (June, July, and August) periods. Positive relations were also determined between the ring width and total precipitation in spring (March, April) and summer (June, July, and August), negative relations being noted between the ring width and the rainfall of May and September. The temperature of March appeared to be the most important meteorological element, which is crucial for the size of tree ring width.

Key words: Scots pine, dendrochronology, dendroclimatology

INTRODUCTION

The tree-ring is a valuable source of information about the climatic conditions of a given region [9]. Though, the reconstruction of climate from the past must be preceded by the recognition of tree sensitivity to its different elements. The chronologies of radial increments of several hundred years have already been constructed for the lowland part of Poland [1, 14]. They can be used as a source of information concerning the climate in the past.

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As, depending on the climatic zone where a pine grew, different elements of the climate constituted factors limiting the radial increment of trees [2, 5, 13, 15].

The aim of the present work was complementary to the studies from lowland [8, 12, 15]. The aim of this research was to determine the influence of climate of Western Carpathians on the width of rings formed by pines growing in this region.

MATERIAL AND METHODS

The investigation covered the moderately warm climatic zone in Western Carpathians, characterized by the average annual temperature of 6^{o}C and average total annual precipitation of 900 mm. The average vegetation period begins in mid-April and ends towards the late October with the precipitation usually exceeding 600 mm. The highest monthly average temperatures reached 15°C in July, decreasing to –5°C in January. The annual mean amplitude was 20°C (Fig.1). The climatic conditions of the total area of Poland being taken into consideration the region may be regarded as fairly humid and cool.

Fig. 1. Map of the investigated sites (dots) and meteorological stations (red triangles) in the study area and climatic diagram of the Carpatians Mts. Legend for the climatic diagrams: monthly total precipitation (bars), average monthly air temperatures (line), average annual temperature (t), annual total precipitation (p)

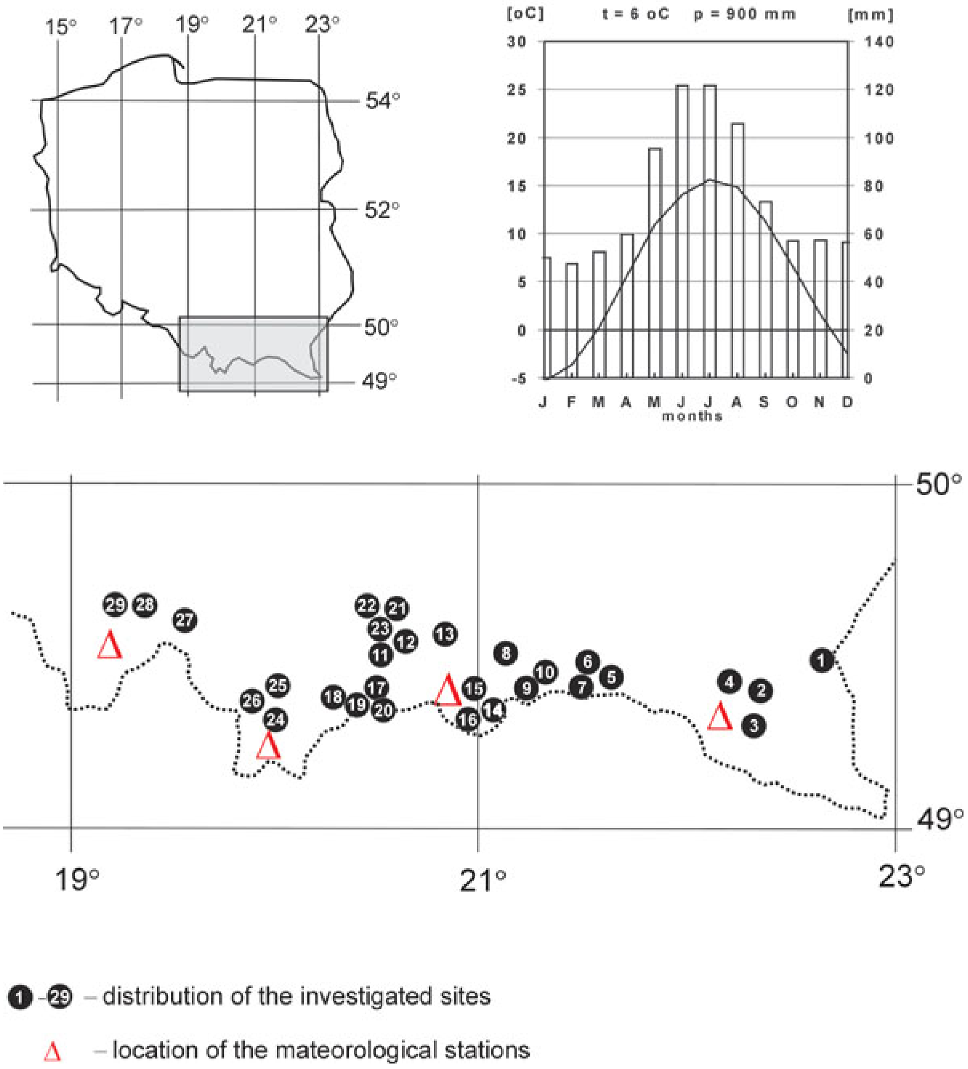

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Table 1. Description of the investigated sites and of the meteorological stations

Site Name	Latitude N	Longitude E	Elevation [m]	Site Types	Soil	Exposure	Slope	Age of the trees
1. ARLAMOW	49° 35’	22° 37’	550	MBF	CMeu	W	5	100
2. CZULNIA	49° 29’	22° 20’	400	UBF	CMeu	WN	5	150
3. CZARNE	49° 18’	22° 15’	700	MMBF	CMdy	SW	15	160
4. MALINKI	49° 31’	22° 18’	350	UBF	CMeu	SE	5	115
5. KREMPNA	49° 32’	21° 26’	550	MBF	CMeu	SW	10	100
6. KOTAN	49° 33’	21° 33’	550	MBF	CMeu	WN	10	105
7. SWIATKOWA	49° 36’	21° 25’	550	MBF	CMeu	SW	10	125
8. BRUNARY	49° 32’	21° 00’	500	MBF	CMeu	S	15	105
9. MAGURA	49° 34’	21° 09’	500	MBF	CMeu	E	15	100
10. WYSOWA	49° 35’	21° 11’	500	MBF	CMeu	NE	15	105
11. JAZOWSKO	49° 35’	20° 30’	500	MBF	CMeu	SE	15	100
12. CHELMIEC	49° 38’	20° 37’	450	MBF	CMeu	WN	15	105
13. LIPNICA	49° 43’	20° 52’	500	MBF	CMeu	SW	10	110
14. SZCZAWICZNE	49° 24’	21° 00’	650	MMBF	CMdy	W	20	130
15. TARTAK	49° 22’	20° 59’	650	MBF	CMdy	E	15	100
16. MAJDAN	49° 27’	20° 42’	450	MBF	CMeu	W	20	120
17. KLODNE	49° 29’	20° 21’	700	MBF	CMdy	WS	35	140
18. PIENINKI	49° 28’	20° 20’	700	MMBF	LPca	S	40	160
19. ZIELONE	49° 25’	20° 19’	550	MBF	LPrz	SE	20	100
20. MACELOWA	49° 22’	20° 15’	550	MBF	LPca	SW	30	120
21. KOSTRZA I	49° 40’	20° 18’	450	MMBF	CMdy	E	15	125
22. KOSTRZA II	49° 39’	20° 19’	450	MMBF	CMdy	NE	15	130
23. STRZYZYC	49° 40’	20° 17’	450	MMBF	CMdy	SE	20	135
24. BOR	49° 25’	20° 03’	600	MCF	HSsa	x	0	120
25. RABKA	49° 38’	19° 58’	500	MBF	CMeu	E	15	105
26. TOPORZYSKO	49° 30’	19° 50’	600	MBF	CMeu	SE	10	105
27. STRYSZAWA	49° 42’	19° 26’	600	MBF	CMdy	W	25	125
28. SLEMIEN	49° 43’	19° 23’	600	MBF	CMdy	S	15	135
29. OKRAJNIK	49° 41’	19° 23’	550	MMBF	CMdy	W	20	115
Meteorological stations								
LESKO	49° 28’	22° 20’	386					
KRYNICA	49° 26’	20° 58’	613					
ZAKOPANE	49° 18’	19° 57’	844					
ZYWIEC	49° 41’	19° 13’	360					
Explanations: Site types: MBF – mountain broadleaved forest, MMBF – mountain mixed broadleaved forest, MCF - moutain coniferous forest, UBF-upland broadleaved forest Soil taxonomy WRB (1998): CMeu – Eutric Cambiosols, CMdy – Dystric Cambiosols, LPca – Calcaric Leptosols, LPrz – Rendzic Leptosols, HSsa – Sapric Histosols								

In each of 29 pine stands selected for the investigation, lying between 400 and 700 m above sea level (Table 1), two samples were taken from the trunks of 20 healthy and dominant trees at the height of 1.3 m above the ground. The samples were used for measurements of the annual growth rings (dendro-scales). The measurements were done (BIOtronik BEPD-4c) with accuracy of 0.01 mm. Each sample provided a sequence of data (chronological series of ring widths for each tree) known as dendro-scales which underwent the process of verification in order to eliminate measurement errors and to detect possible increment anomalies (double, false, discontinuous annual rings). This procedure was used by COFECHA computer program [11]. After that, time

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synchronisation of increments from all trees was carried out. The homogeneity of 560 dendro-scales was tested using the nonparametric percentage of agreement (GL) [7] beetwen each dendro-scales:

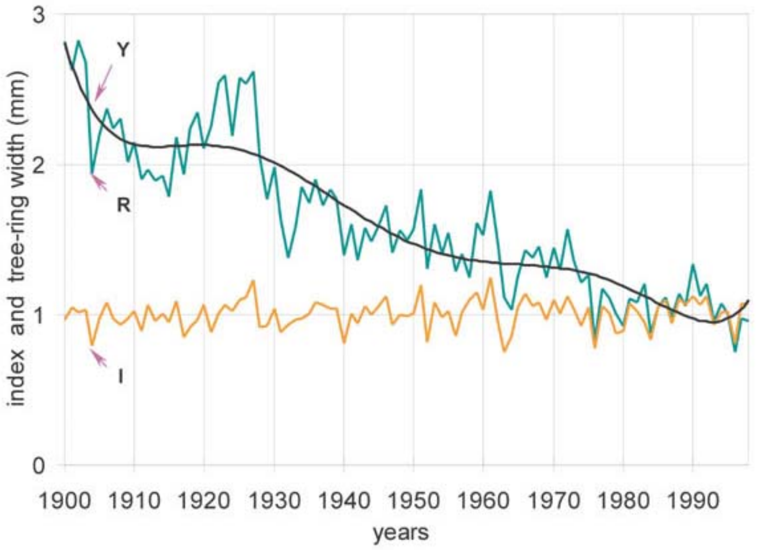
$$GL = 100\ m\ (n-1)^{-1}\ [\%]$$

where:

m - number of convergent (increase/decrease from year to year) sections of the compared dendro-scales, n - number of years compared.

Their highly significant ($P<0.01$) similarity permitted the use of program ARSTAN [6] in the calculation of chronology as an average from all the 580 dendro-scales. It represented the entire investigated region. The calculation included both the tree-ring chronologies and the indexed chronologies (Fig.2).

Fig. 2. Chronology of tree-ring width and curve of regression (green and black lines), indexed chronology (yellow line). Y – value of the curve of regression, R – width of growth ring, I – increment index



The ARSTAN programme was used to standardise the dendro-scales (values R_i) by calculating matching curves of regression (values Y_i) and by calculating increment indices (values I_i):

$$I_i = R_i / Y_i$$

where:

R_i - width of growth rings in year i,
Y_i - value of the curve of regression in year i (Fig. 2).

The chronology stresses the common traits characteristic of the dendro-scales composing it. At the same time it weakens their individual variability associated with the effect of weaker environmental factors. The aim of the standardisation procedure was to eliminate from the dendroscales long-therm fluctuations in growth rings caused by short-therm fluctuations modeled for the climatic factors [9].

Analysis of connections between the climate and the radial increment was conducted in three stages. At first, the estimation conducted on the basis of multiple regression method – response function – [9, 3] concerned the effect of air temperature and precipitation on the tree-ring width. The independent variables were mean monthly air temperatures and total monthly precipitation from October of the year preceding the increment to September of the year when the increment occurred. Data averaged from four Carpathian meteorological stations for the years 1900-1998 were used to represent the given region (Fig.1). The dependent variables were the values of increment indices of the indexed chronology.

At a further stage of the work the pattern of the regional ring width chronology was compared with curves of changes of various climatic elements in different seasons of the year. The use of the same GL convergence index permitted the evaluation of the similarity (convergence) degree in searching for the highest convergence indices. In that case the ring width chronologies (increase/decrease from year to year) were compared to the curves of various climatic elements.

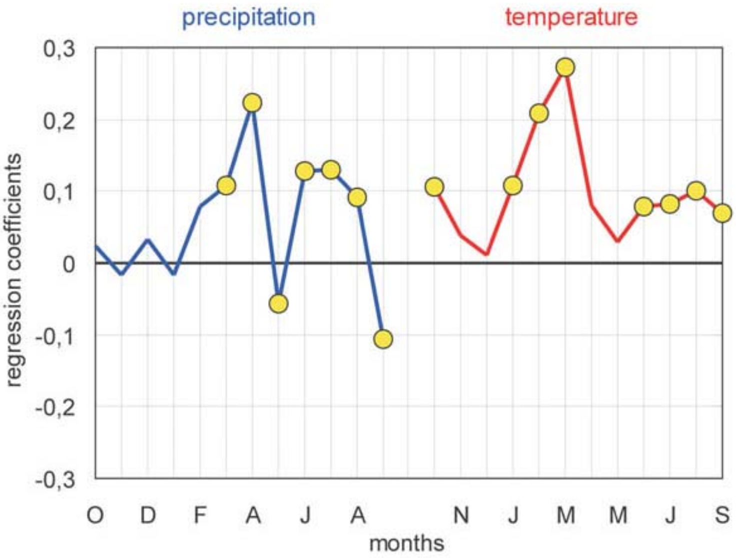
Then, with the use all of dendro-scales the percentage of trees which in the different years produced rings narrower or wider in relation to the rings of a preceding year, was estimated. Their relative changes (%) were calculated.

For the selected pointer years i. e. those in which a increase or decrease occurred in the tree-ring widths of more than 95% of the sampled trees, meteorological conditions of months before and during the vegetation period were analysed to find relationships with the increment response of the trees.

RESULTS AND DISCUSSION

The results of analysis of the response function show that in the years 1900-1998 temperature and rainfall conditions of the vegetation period and of the months preceding it significantly affected the tree-ring width. Regression coefficients were considered to indicate months whose temperature and rainfall significantly ($P<0.05$) effected the annual increment. High temperatures of October of the preceding year, of winter (January, February, and March) and summer (June, July, and August) months positively affected the width of tree-rings. Similar positive effects were recorded in the case of abundant precipitation in spring (March and April) and summer (June, July and August) while high precipitation in May and September negatively affected the radial increment (Fig.3). The highest positive effect of the temperatures of March on the tree-ring width should be stressed. The warm and dry weather of September also positively affected the cambial activity of pine trees (Fig.3), this being reflected in the greater width of tree-rings.

Fig. 3. Regression coefficients of average rainfall and temperature against average tree-ring width for the period 1900 to 1998 for each month from October (O) of the previous year to September (S) of the current year. Open circles indicate when $P \le 0.05$



The chronology of tree-rings showed the highest GL index of convergence with the curve of average March temperatures (Fig.4). GL index amounted to 75% ($P<0.01$). This confirms the significant effect of the temperature conditions of March on the activity of cambium in the following months, evidenced by analysis of the response function (Fig.3). It should be remembered that in March the divisions of cambium cells do not occur yet. In the investigated region they only begin early in May.

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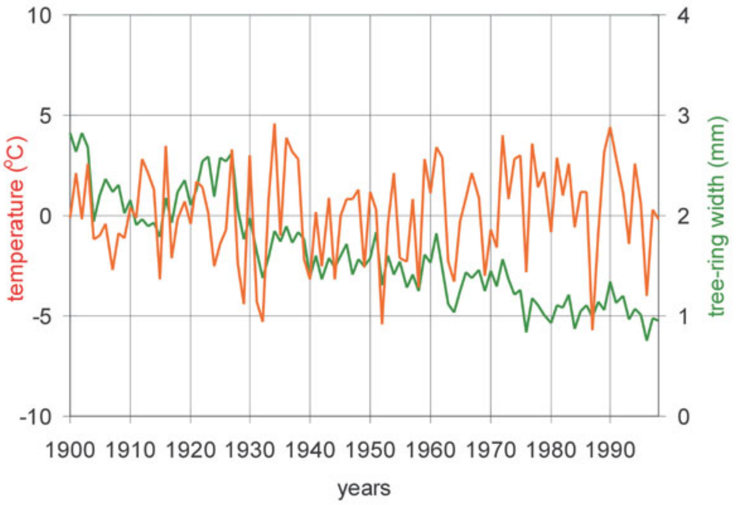
Fig. 4. Tree-ring chronology (green line) and the average March temperatures (red line)



Analysis of changes in tree-ring width showed that in six positive-pointer years there was an increase in increment in more than 95% of the sampled trees. These years were 1922, 1953, 1961, 1965, 1977, and 1985. Similarly there were seven negative-pointer years which showed a decrease in increment in more than 95% of the sampled trees. These years were 1904, 1928, 1931, 1940, 1952, 1956, and 1963 (Fig.5). The average change in tree-ring width was not great, reaching a maximum value of 40% in 1977 (Fig.5).

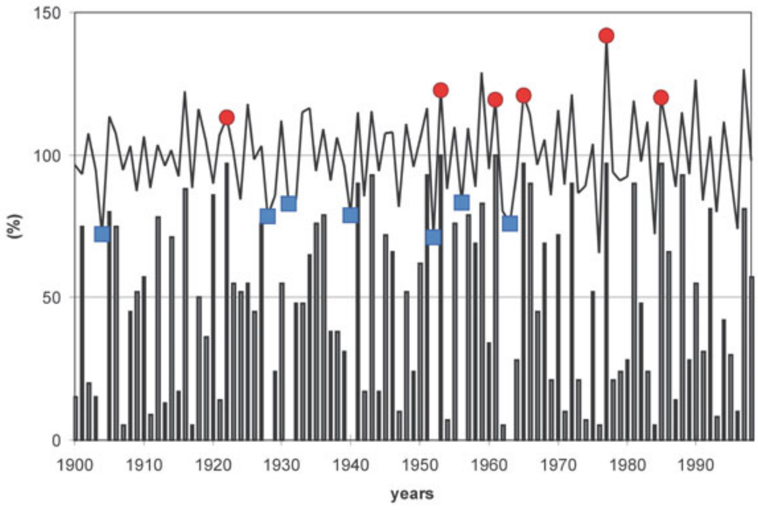
Analysis of the temperature and rainfall conditions (Fig. 6) in the positive-pointer years shows that:

in 1922 the positive effects on the size of radial increments of the investigated trees can be attributed to warm March, June, and July despite dry summer;

in 1953 to warm and humid summer (June and July);
in 1961 to warm February, March and June despite low precipitation in summer;
in 1965 to high precipitation in summer (June-August) despite frosty winter;
in 1977 to warm January, February and March despite cool and dry summer;
in 1985 to warm March and high precipitation in summer despite frosty winter.

Thus in each year slightly different elements of the climate positively affected the increment, compensating negative effects of the remaining elements. Though in those years March was always among warm months or summer was characterized by abundant rainfall. Therefore, the favourable system of meteorological variables mentioned above significantly and positively affected the size of radial increments.

Fig. 5. Percentage of trees with increased width of tree-ring compared to the previous year (bars). Relative change in tree-ring width from year to year (line) for the same period. Positive pointer years (red filled circles) and negative pointer years (blue filled squares)



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All the investigated trees (100%) developed narrower rings in years with frosty March and fairly dry summer (June and July). This occurred in the years 1904, 1928, 1931, 1952, 1956, and 1963. On the other hand abundant rainfall in 1940 did not suppress the unfavourable decreasing tendency in the increment brought about by the very long and frosty winter (Fig.7).

Fig. 6. Temperature and rainfall deviations each month for positive pointer years – October to December in the previous year and January to September in the present year. Deviations of mean monthly temperatures from the average values (red bars). Deviations of monthly total precipitation from the average values (blue line)

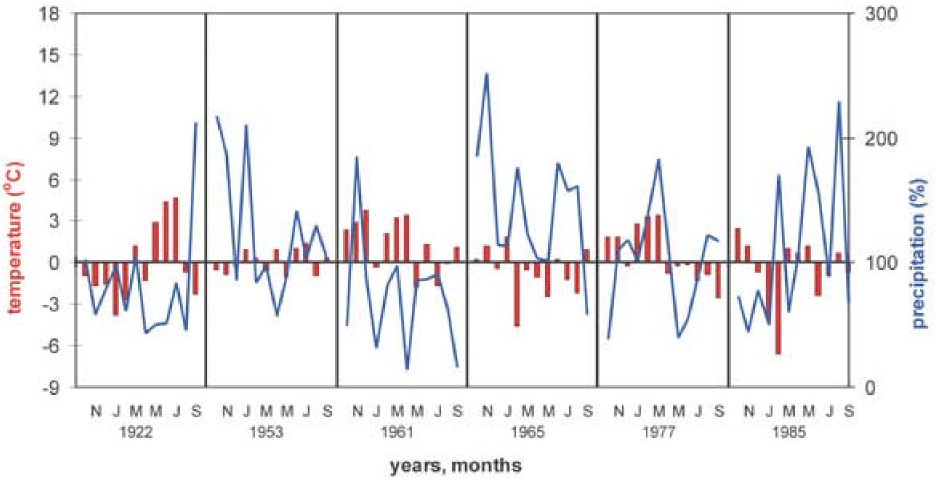
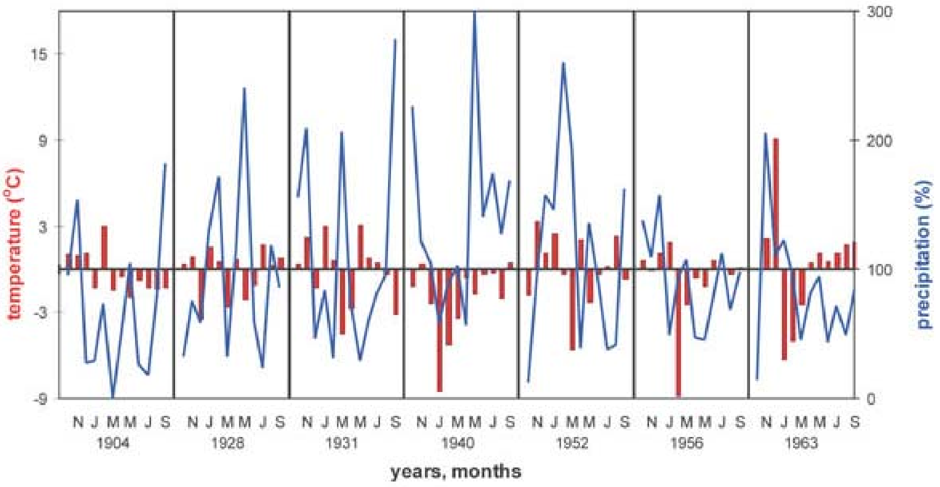


Fig. 7. Temperature and rainfall deviations each month for negative pointer years – October to December in the previous year and January to September in the present year. Deviations of mean monthly temperatures from the average values (red bars). Deviations of monthly total precipitation from the average values (blue line)



The current results of dendroclimatological studies on Scots pine show that on the northern border of its distribution range the chief factors limiting the radial increment are low temperatures during the vegetation period [2, 4]. On the southern border the limiting factor is the deficiency of precipitation [10, 13]. In the temperate climate of Central Europe (lowland) the response of pine trees growing here to frosty winters and dry summers is reduced increment [8, 12].

The results presented in the work confirm the sensitivity of pine from this region to the termal conditions of the winter and rainfall in the summer. They also stress the highly significant effect of air temperature in March on the radial increment.

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CONCLUSIONS

1. The tree-ring width is the final effect of a complex of various climatic factors whose action is frequently in opposition.
2. Pine trees growing in fairly cool and wet Western Carpathians were sensitive to the temperature and rainfall factors of the vegetation season and months preceding it.
3. In this altitudinal and geographical zone average increment response of trees is fairly small. The average relative change in ring width did not exceed 40%.
4. In at least 95% of trees an increase in tree-ring width occurred in years when the winter seasons were warm or the summer rainfall exceeded the average. Pine trees from this region form narrow rings in years with long and frosty winters and dry summers.
5. The temperature of March appeared to be the most important meteorological element, which is crucial for the size of tree ring width.

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