RELATIONSHIP OF TREE-RING WIDTHS IN THE TATRA MOUNTAINS TO VARIATIONS IN MONTHLY TEMPERATURE AND PRECIPITATION

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SUMMARY

Presented are the results of investigations on the dependence between the tree-ring width in stone pine (Pinus cembra L.) mountain pine (Pinus montana Mill.), sycamore maple (Acer pseudo-platanus L.) and Carpathian birch (Betula carpatica W.K.) from the Tatra Mts, upon mean monthly air temperatures and totals of monthly precipitations in the period from about 1910 to the present.

In spite of certain differences, favourable effect of high temperatures of air in summer months, particularly in June and July, of the current growing season and also of the growing season in the previous year, on the width of tree-rings was observed.

High totals of atmospheric precipitations in summer of the current year and of the previous growing season affected unfavourably the formation of tree-rings.

I N T R O D U C T I O N

Considering the multiform influence exerted by climate on tree growth, the methodological problems the dendroclimatologists have to solve are far from easy. In fact, each separate factor within this complex influence has varying intensity, and thus affects at times more, at other times less, the growth of trees.

Further, the respective effects of particular factors can mutually concur, overlap, eliminate each other etc.

The situation becomes much simplified in extreme climatic conditions, where the decisive effect on life processes of tree growth is exerted by factors at extreme intensity - at their maximum or minimum value.

This was the main basis upon which the pioneer successes and the later achievements in American dendroclimatology were based American researches have had recourse in their work to trees growing in the arid lower forest border (Schulman 1956, Fritts 1974, 1976 and others). In this environment, narrow rings are associated with low precipitation and high temperatures.

At the subarctic treeline, the temperature during the warmest months are correlated with tree-ring width (Eklund 1957, Hustich 1945, 1948, Mikola 1962, and others).

Another area which has aroused the interest of dendroclimatologists is the alpine timberline, where the main climatic factor limiting tree growth is low air temperature during a short growing season. This can be distinctly seen both from the results of the previous investigations on dendroclimatology (Artmann 1949, Bednarz 1976, Brehme 1951, Ermich 1955, Feliksik 1972, LaMarche and Fritts 1971, Schweingruber et al. 1978) and those of observations made on the intensity of photosynthesis in trees growing at high mountain sites (Tranquillini 1957, 1964, 1967).

E X P E R I M E N T A L   M E T H O D S

O b j e c t   o f   r e s e a r c h

It has been the object of the present research to determine to what extent the average monthly air temperatures and total monthly precipitations of the current year and of that directly preceding it affect the tree-ring width of stone pine (Pinus cembra L.), mountain pine (Pinus montana Mill.), Carpathian birch (Betula carpatica W.K.) and sycamore maple (Acer pseudoplatanus L.) in the Tatra Mts.

M a t e r i a l

In our research we have taken into consideration the species which in the course of historical processes of transformation undergone by the Tatra forests had spread to the highest stations accessible to trees in the subalpine mountain pine zone and in the alpine timberline. The sycamore maple alone, although being also a mountain species, comes from the lower situated habitats of the lower forest zone. The principal data on the habitats of the tree species under investigation have been ploted on Table I.

M e t h o d

The investigation was carried out on the samples taken with Pressler increment borer. From each tree two to four cores were taken and the annual rings of the period 1890-1976 were measured. For each tree the mean value of the annual growth was computed, and on this basis the dendrochronological curves of the investigated trees were plotted. After crossdating the curves the mean tree-ring chronology for each species and separate locality were calculated,

Table I. The principal data concerning the investigated trees

Species	Locality	Elevation /m/	Exposure	Forest community	Number of trees
Pinus cembra L.	Polish Tatra Mts.				
	Sucha Kasprowa Valley	1500	N	Cembro-Piceetum	65
	Zabie near M.Oko	1450-1620	N	Cembro-Piceetum	32
	Wołoszyn	1450-1500	NE	Cembro-Piceetum	5
Pinus montana Mill.	Polish Tatra Mts.				
	Hala Gasienicowa + Sucha Kasprowa Valley	1600	N	Pinetum mughi silicolum	60
	Slovakian Tatra Mts. Lemnický	1600	SE	Pinetum mughi silicolum	70
Betula carpatica W.K.	Slovakian Tatra Mts. Slavkovský	1500	SE	Pinetum mughi silicolum	16
Acer pseudoplatanus L.	Polish Tatra Mts.				
	Białege Valley	950	N	Dentario glandulosae-Fagetum	36
	Roztoki Valley	1300	SE	Aceretum	10

and master dendrochronological curves were plotted. To determine the degree of dependence of the tree-ring width of the tree species under investigation upon climatic factors recourse was made to the percentage coefficient of agreement, the coefficient of correlation, simple linear regression and "response function" method.

The percentage of agreement describes the percentage of cases in two series tree-ring chronology and monthly climatic data in which the change from the value of the prior year is in the same direction. If there is no change in one series that case is counted as 0.5. The percentage of agreement is calculated according to the formula:

$$P_a = \frac{n^+}{n} \cdot \frac{100}{1}$$

were

P_a = percentage of agreement

n^+ = number of agree sectors of two compared curves

n = total number of compared series or sectors of curves

Ideal similarity of curves occurs at P_a = 100 %, the absence of similarity is indicated by P_a = 0 %.

If two curves (series) vary at random and are of infinite length, the expected percentage of agreement is 50 %.

The multiple linear regression, called response function, used in this study for Pinus cembra (see Figure 4, 5) is essentialy that one developed at Laboratory of Tree-Ring Research, Tucson and described most recently by Fritts (1976).

On the basis of tree-ring measurements the ring-widths for each tree were transformed to ring-width indices using either an exponential curve or straight line of zero or negative slope (Fritts 1963, Fritts et al. 1969). This transformation is designed to remove the effects of differences in average growth rates between trees, as well as biological age trends. A response function was calculated for two chronologies of Pinus cembra from Polish Tatra Mts. (Figure 4, 5). Each response function includes 14 weights for average monthly temperatures and 14 weights for monthly precipitation from June of the year prior to the season of growth through the July concurrent width growth. Three additional values are associated with prior ring-width index at lags of 1, 2, and 3 years. A positive weight indicates a direct relationship of the climatic variable or prior growth variable to ring-width, and a negative weight indicates an inverse relationship. The vertical lines designate the 0.95 confidence level.

In general, the results of the response function, percentage of agreement, coefficient of correlation and sample linear regression are similar, although there are some differences.

C l i m a t i c   D a t a

A basic condition facilitating dendroclimatical research is to have a stock of long-term meteorological observations performed in a close neighbourhood of trees used for investigations. In the Polish Tatra Mts., these conditions are met by the station at Zakopane (844 m above sea level) which has the longest series of meteorological observations comprising nearly complete records, from 1900 up to the present day.

R E S U L T S

P i n u s   c e m b r a   L

A comparison of curves for the climatic elements for Zakopane, with an average annual-growth curve of the stone pine from the Sucha Kasprowa Valley, Zabi near M.Oko and Wołoszyn, point to an evident dependence of its growth, mainly on thermal conditions of the vegetation period (Figure 1,2,3). The relation between the ring-width and mean air temperature of June to July in the period of time from

1911 to 1965 is characterized by an eightly percentage of agreement and by the correlation coefficient $r_{xy}=0.772 \pm 0.052$ (Figure 1,2,3).

On the basis of the relation between the mean air temperature of the months June and July (x) and the width of annual increments of the stone pine rings (y) determined by the linear regression equation $x = 8.13 + 0.202y$, the approximate course of temperature variability of June and July in the Polish Tatra Mts. was reconstructed for years 1740 to 1910 (Bednarz 1976).

The dendroclimatological analyses carried out in the present study have shown that tree-ring width of the stone pine were positively affected by high air temperature from May to August of preceding year. On the other hand, low air temperature from December of the previous year to April of the current year, restrict the growth of thickness (Figure 3). The analysis of the response function seems to lead to almost identical conclusions (Figure 4,5).

The step of the regression shown in Figure 4 accounted for 83 % of the total variance, of which 28.3 % was described by the climatic elements and 54.7 % by the prior growth. This response function indicates that large rings are correlated with high temperatures in June, July and February of the current growing season and August to October of the previous year (a direct relationship).

The variance explained by climate for Pinus cembra from Zabie near M.Oko is 33.8 % and that explained by prior growth 56 % making a total of 90.1 % (Figure 5). The weights for temperature in the prior August to October and current February and May to July are positive and highly significant. In March of the current year and July of the previous growing season the temperature relationships are inverse.

As it results from dendroclimatological analyses, a vital factor in the process of tree-ring formation of the stone pine are the temperature conditions in the months of June and July, which can be considered as the period of the most intense growth of thickness, whereas the effect of air temperature in May and August is much less prominent (Figure

3,4,5). Identical conclusion can be drawn from the results of Tranquillini's research on the annual course of photosynthesis in the stone pine in the Tyrolese Alps (Tranquillini 1957, 1964, 1967). That there is a strict dependence of the tree-ring width of stone pine upon the thermic conditions of summer months May to August has been shown for the Alps by Artmann (1949), LaMarche and Fritts (1971), Schweingruber (1978) and for the East Carpathian Mts. by Koliščuk and Berko (1967).

The analysis of the dependence of the stone pine tree-ring width on precipitation has revealed a limiting effect exerted by its high totals in the summer season, particularly in June - July upon the growth (Figure 1,3,4,5). It is the rule that in the years when the precipitation total is unusually high in the May to August period, as it was, for instance, in 1913, 1934, 1949, 1960, the tree-rings are narrow, while in the years with poor precipitation, as for instance, in 1911, 1917, 1939, they are thick (Figure 1). An inverse dependence of stone pine growth on precipitation during May to August has been corroborated by the results of Artmann (1949), Schweingruber (1978) and Koliščuk and Berko (1967). They attribute the cause of reduced stone pine growth in rainy years to thermic depressions accompanying precipitation in the mountains. As can be seen from Figures 3,4 and 5, apart from the high totals of summer precipitation in the current year, the reduction of the tree-ring width is also dependent on precipitation in the months of September and October of the previous year. In August of preceding growing season the precipitation relationship was direct and highly significant.

Pinus montana Mill

The dendroclimatological analyses carried out in the present study (Figure 6,7) indicate that the width of mountain pine tree-rings is directly affected by high air temperature in May to July (August) of the current growing season as well as in May to November of the previour year. Low temperatures, from December of the previous year to April of the current one, exert a limiting effect on growth. This also applies to temperatures from January to April in the previous year. That there is a strict direct correlation between the mountain pine tree-ring width in the East Carpathian Mts. and air temperature from May to August, has been pointed out by Koliščuk and Berko (1967). Precipitation in the months of May to July of both the current and previous growing season reduce the width of tree-rings similary as it was the case with the stone pine.

An analogical phenomenon has been found to occur in the East Carpathians Mts. (Koliščuk and Berko 1967). There is an unfavourable effect upon the growth of the precipitation of the summer months (June to August) of the previous year. This refers particulary to June. On the other hand, a direct correlation with the width of mountain pine tree-rings can be noticed for the precipitation of February and March, both in the current and previous year.

B e t u l a   c a r p a t i c a   W   K

As it appears from analyses, a decisive effect upon the width of tree-rings of the Carpathian birch is exerted by air temperature from May to July of the current year (Figure 8). Another factor stimulating the growth of Carpathian birch tree-rings is high air temperature from October to December, and from April to May of the previous year.

A c e r   p s e u d o p l a t a n u s   L

The results of dendroclimatological analyses show a high direct correlation between the width of tree-rings of sycamore maple in the Tatra Mts. and air temperature from May to August in the current growing season (Figure 9). A direct correlation, although a less distinct one, can be also stated for the periods of May to June and October to

February of the previous season.

The width of the sycamore maple tree-rings is unfavourably affected by the high totals of precipitation in the months of May to July of the current growing season, and April to July of the previous year. There is a direct, though hardly marked, correlation between the width of these tree-rings and precipitation in the month of March of the current year and of March, July, August and October of the previous one.

CONCLUSIONS

1. A comparison of the average tree-ring width of stone pine with the meteorological data for station Zakopane shows that there is a marked dependence of annual increment on the thermic conditions of summer months, and in particular on mean air temperature in June and July. The dependence of tree-ring width on the mean air temperature of that period in the years 1911 to 1965 is expressed by an eighty percent coefficient of agreement and by the correlation coefficient $r_{xy} = 0.772 \pm 0.052$.

2. The high totals of precipitation in summer season, and in the months of June to July in particular, have a restricting influence on growth.

3. The width of tree-rings of mountain pine in the Tatra Mts. has shown to be directly correlated with air temperature from May to July (August) of the current year, and May to November of the previous one. The high totals of precipitation in the months of May to July of the current and past years restricted growth.

4. A decisive effect upon the width of tree-rings of

Carpathian birch is exerted by air temperature from May to July of the current year.

5. The width of tree-rings of the sycamore maple shows a high direct correlation with the mean monthly air temperatures from May to August of the current year. An unfavourable effect upon tree-ring width is exerted by the high totals of precipitation in the months of May to July of the current growing season and April to July of the previous one.

6. Despite differences from one tree species to another, the general character of the dependence of tree-ring width upon air temperature and precipitation is similar regardless of the tree species. This enables us to draw the conclusion that the influence exerted by these climatic factors is decisive for the processes of radial growth of trees in the higher mountain sites in the Tatra Mts. (Figure 10).

A C K N O W L E D G E M E N T

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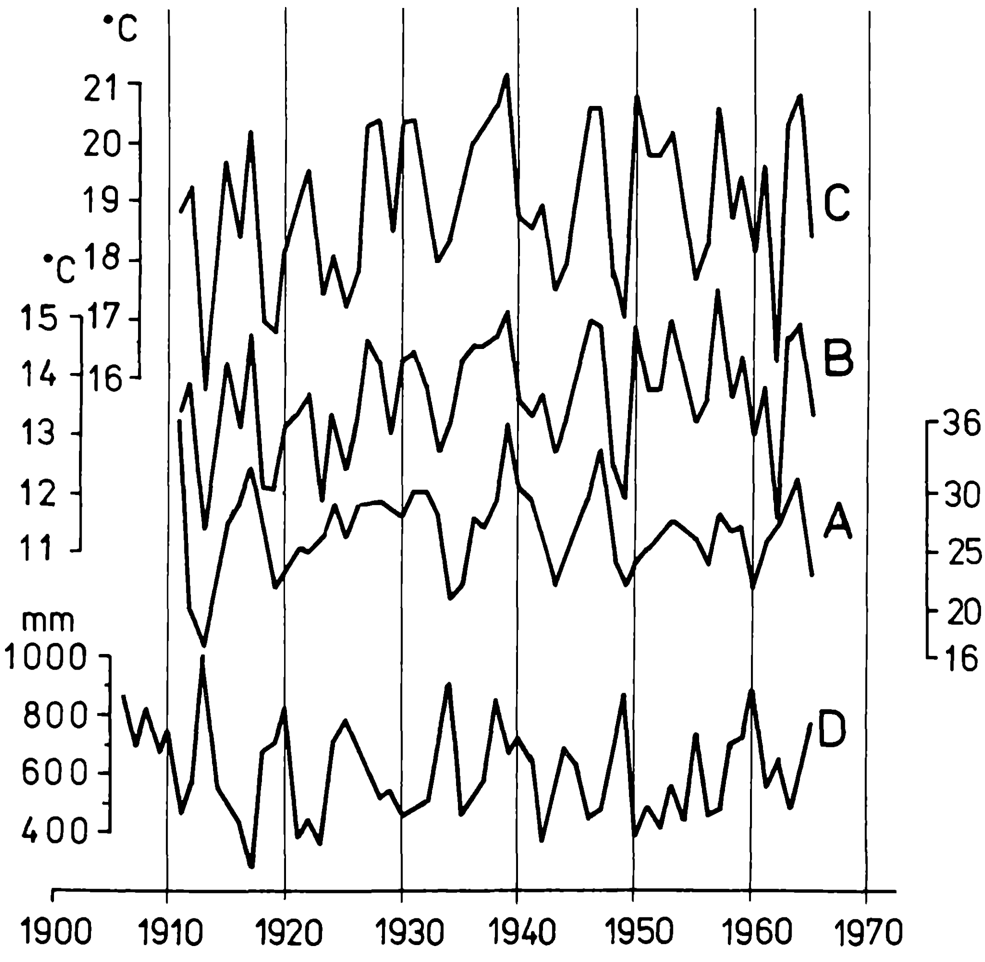

Figure 1. Comparison of mean ring-width chronology of Pinus cembra - A with curves for average temperature of air in the months June - July - B, average maximum temperature of air in the months June - July - C and sums of precipitations from May to August - D.

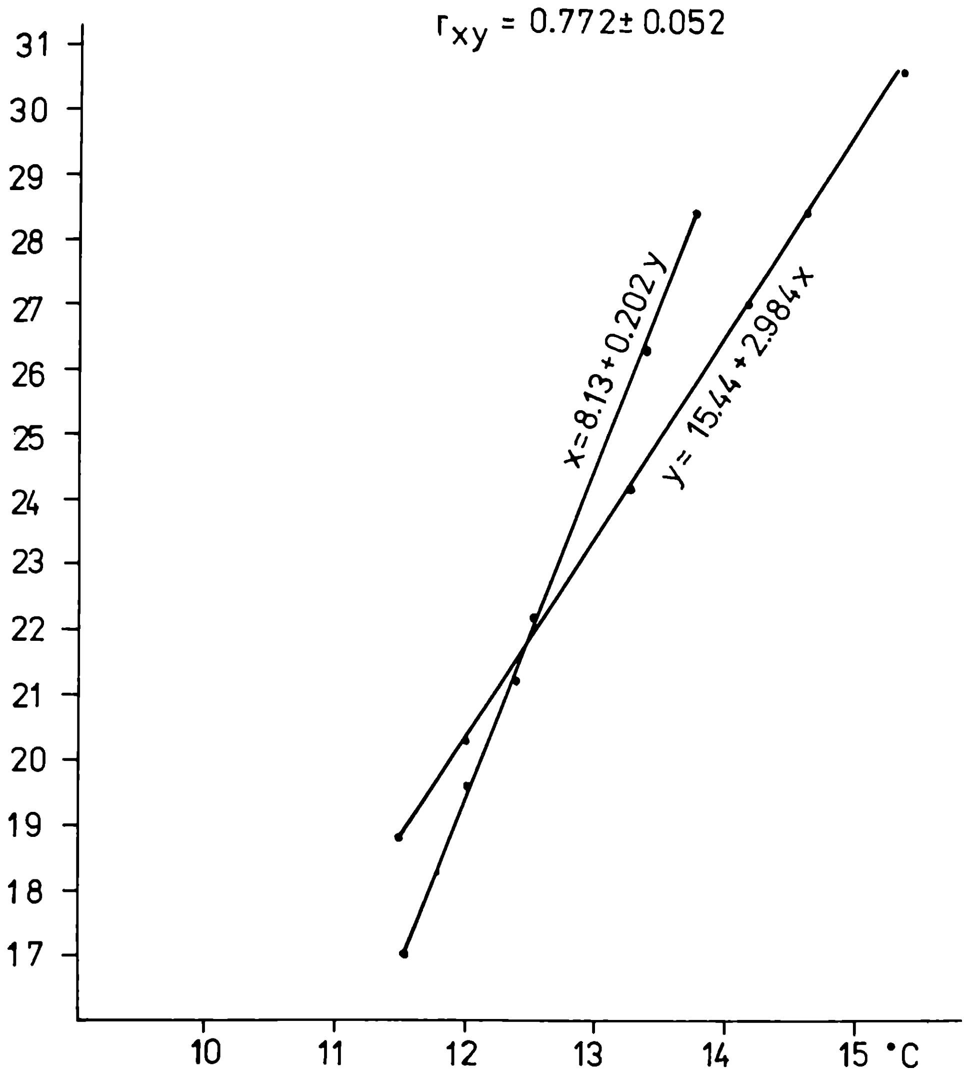

Figure 2. Relation between growth rings of Pinus cembra (y) from Sucha Kasprowa Valley in the Tatra Mts. and average temperatures of air from June to July (x) expressed by linear regression for period 1911 - 1965.

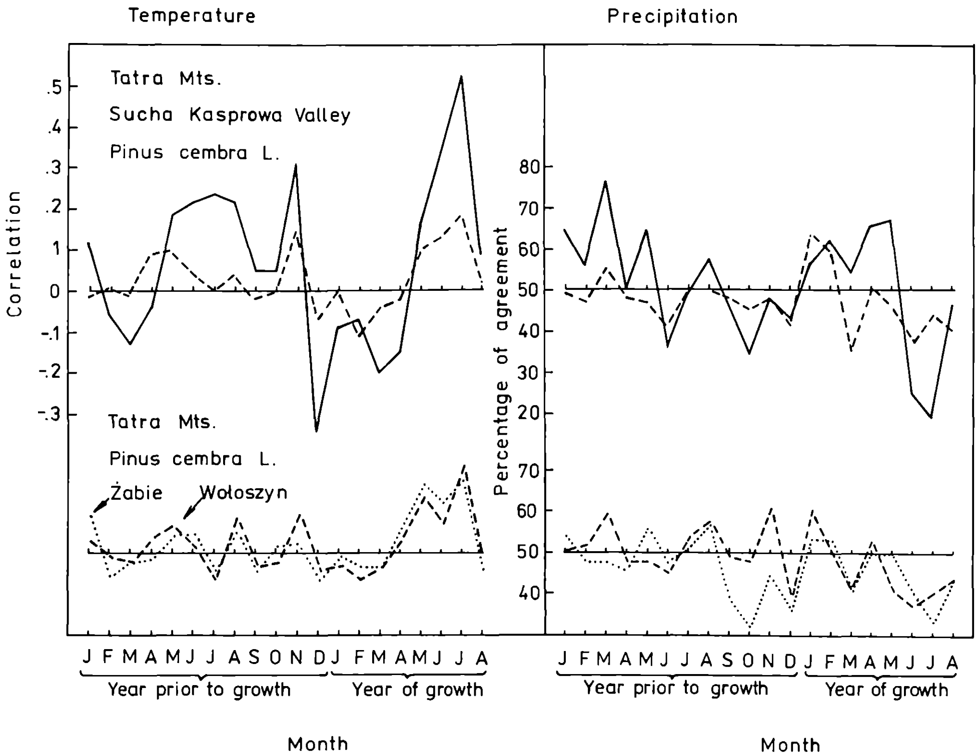

Figure 3. Relation between mean ring-width chronology of Pinus cembra from Polish Tatra Mts. and average monthly temperatures and total monthly precipitation, expressed by coefficients of correlation (solid line) and percentages of agreement (dashed line). The interval of analysis of 1911 - 1965 for temperature and 1896 - 1900, 1906 - 1965 for precipitation (53 and 63 degrees of freedom for the correlation).

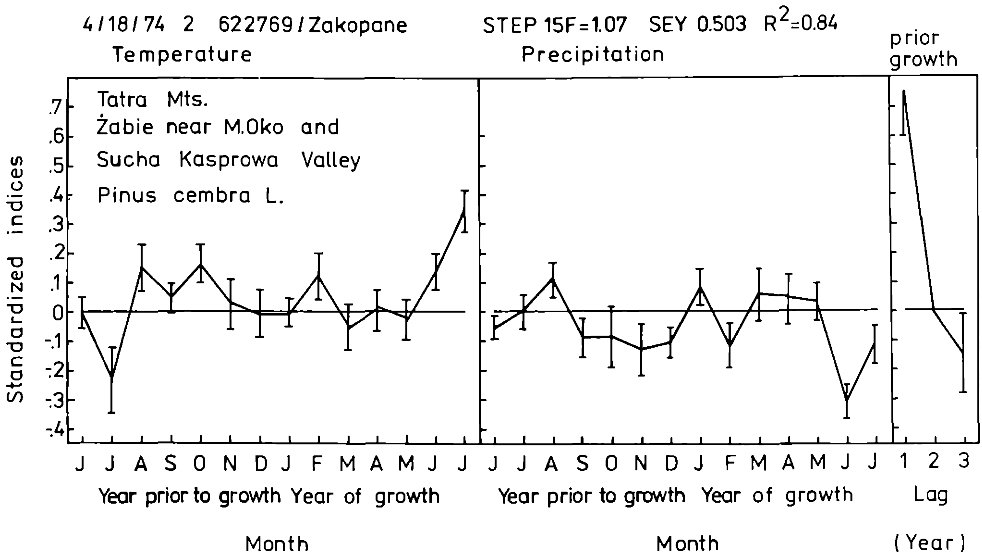

Figure 4. Results of step 15 of response function analysis: ring width indices for Pinus cembra from Polish Tatra Mts., regressed on principal components of average monthly temperatures and total monthly precipitation value from Zakopane and three years of prior growth indices. The vertical lines designate 95 % confidence level. Total variance is 83 %. The variance explained by climate is 28.3 %.

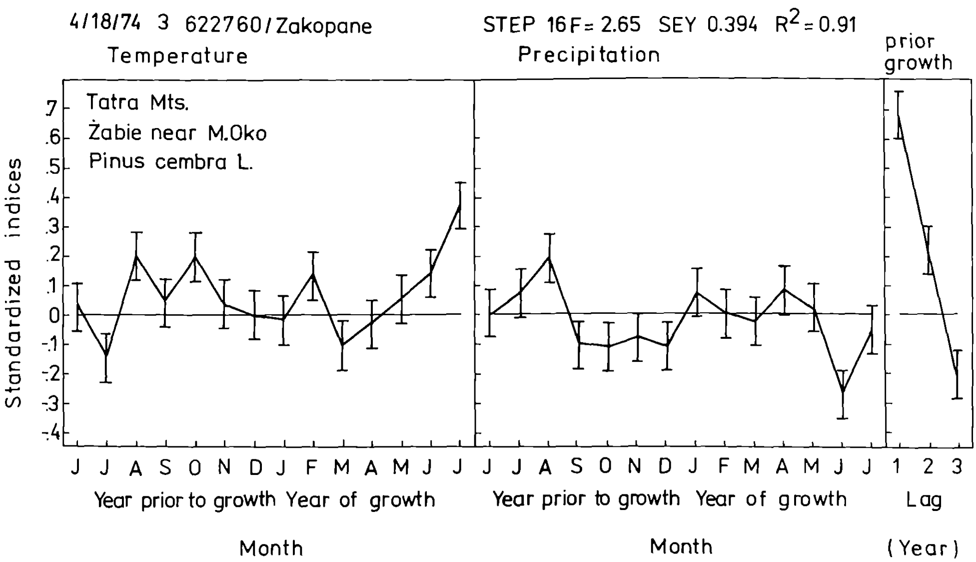

Figure 5. Results of step 16 of a response function analysis: ring width indices for Pinus cembra from Polish Tatra Mts., Zabie near M.Oko, regressed on principal components of average monthly temperatures and total monthly precipitation value from Zakopane and three years of prior growth indices. The vertical lines designate 95 % confidence level. Total variance is 90.1 %. The variance explained by climate is 33.8 %.

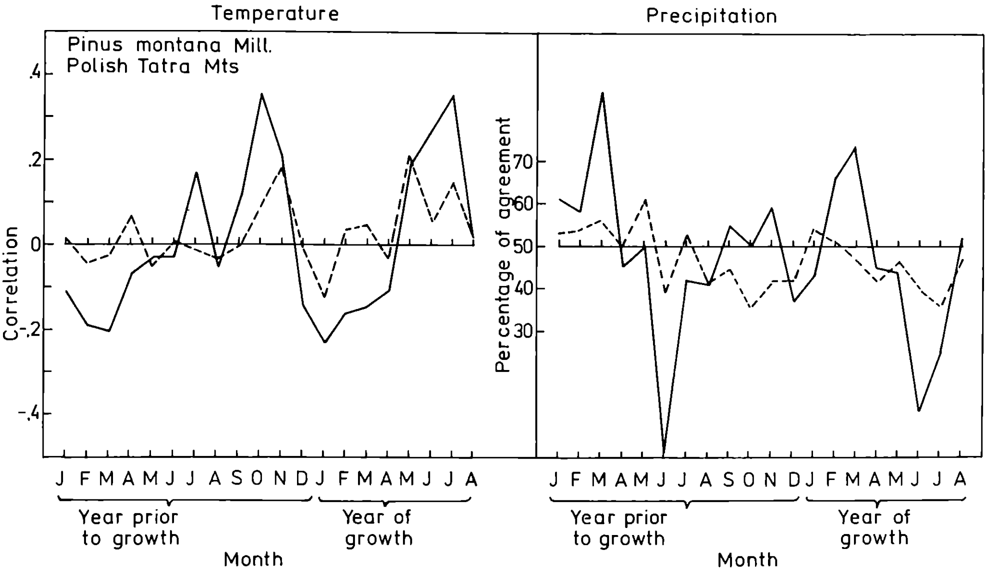

Figure 6. Relation between mean ring-width chronology of Pinus montana from Polish Tatra Mts. and average monthly temperatures and total monthly precipitation, expressed by coefficients of correlation (solid line) and percentages of agreement (dashed line). The interval of analysis is 1911 - 1976 for temperature and 1896 - 1900, 1906 - 1976 for precipitation (64 and 74 degrees of freedom for the correlation).

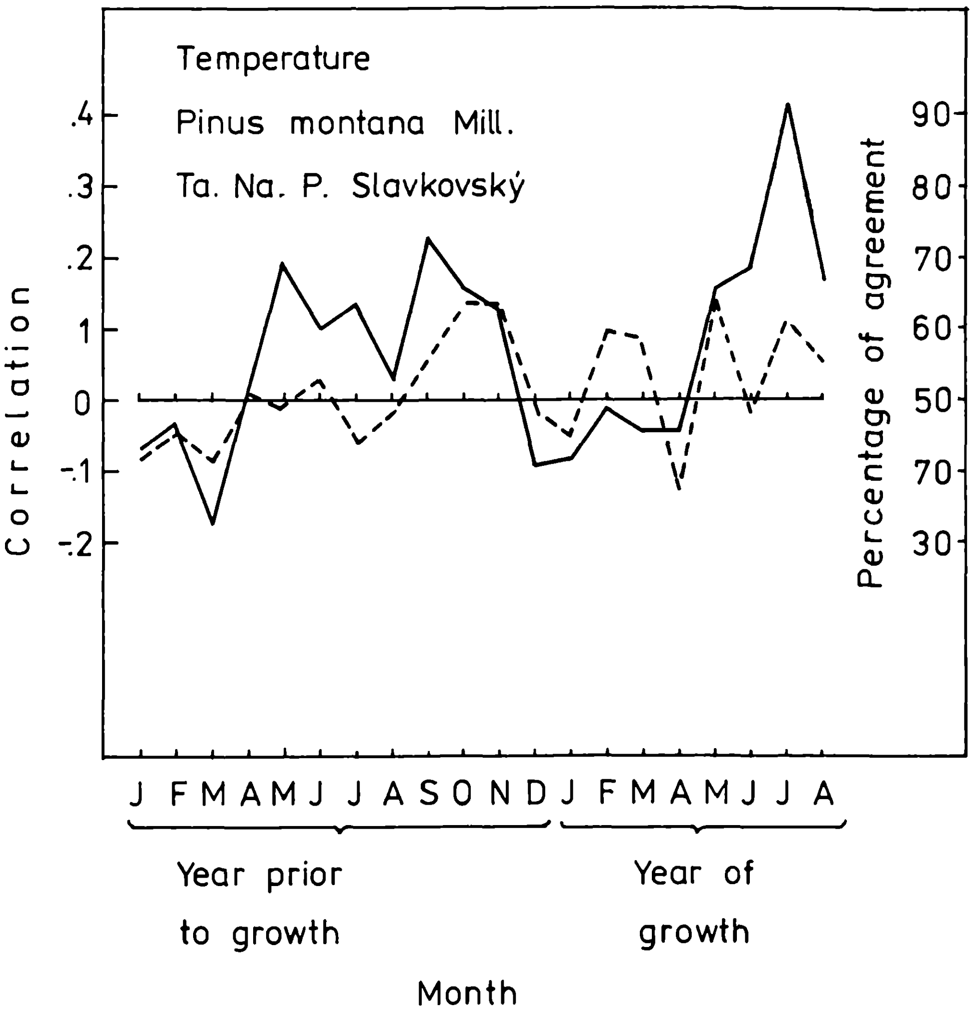

Figure 7. Relation between mean ring-width chronology of Pinus montana from Slovakian Tatra Mts. and average monthly temperatures, expressed by coefficients of correlation (solid line) and percentages of agreement (dashed line). The interval of analysis is 1911 - 1976 (64 degrees of freedom for the correlation).

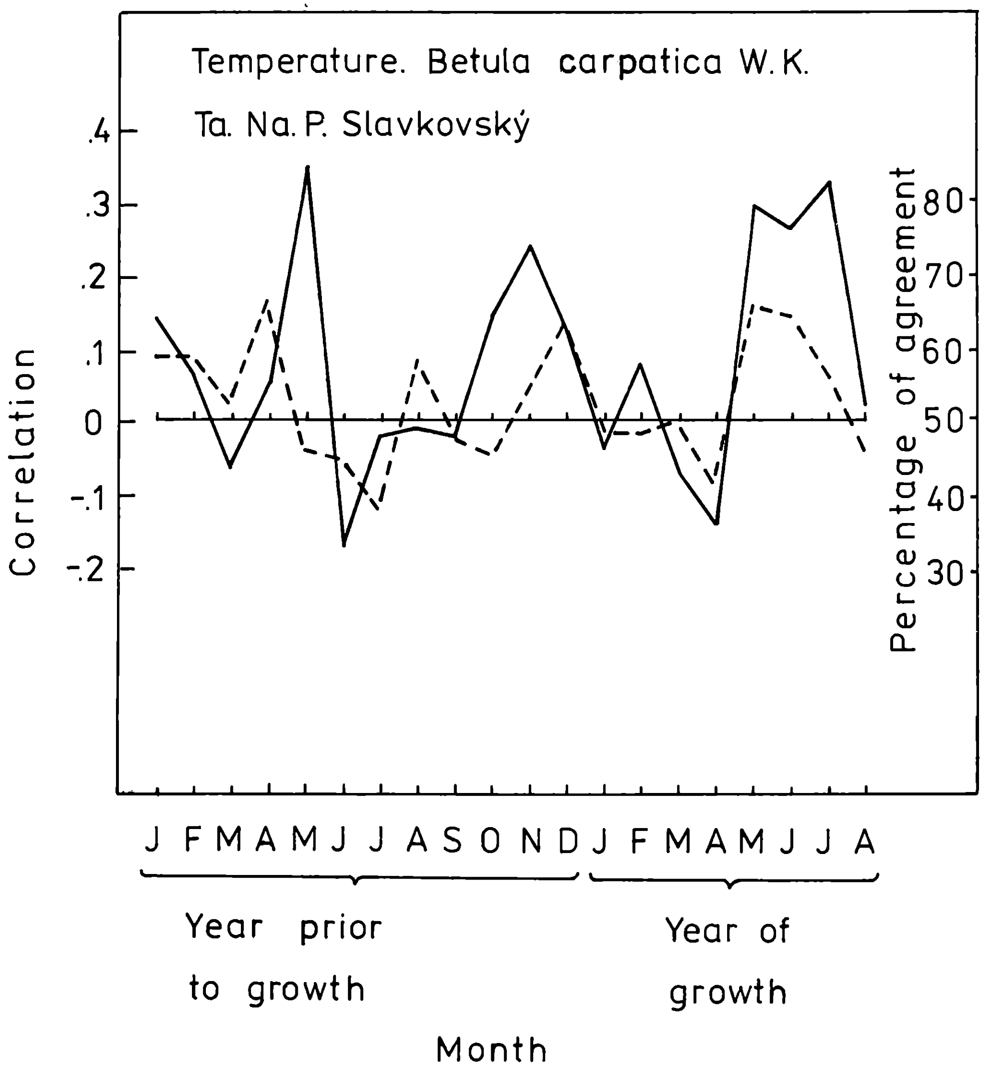

Figure 8. Relation between mean ring-width chronology of Betula carpatica from Slovakian Tatra Mts. and average monthly temperatures, expressed by coefficients of correlation (solid line) and percentages of agreement (dashed line). The interval of analysis is 1911 - 1976 (64 degrees of freedom for the correlation).

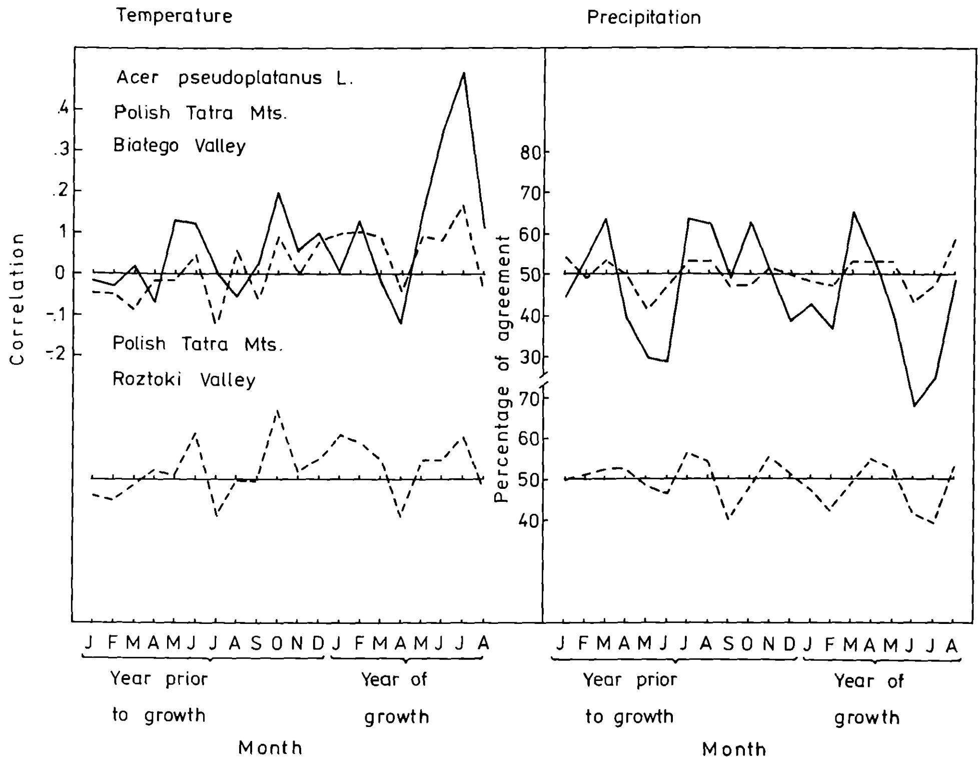

Figure 9. Relation between mean ring-width chronology of Acer pseudoplatanus from Polish Tatra Mts. and average monthly temperatures and total monthly precipitation, expressed by coefficients of correlation (solid line) and percentages of agreement (dashed line). The interval of analysis is 1911 - 1976 for temperature and 1896 - 1900, 1906 - 1976 for precipitation (64 and 74 degrees of freedom for the correlation).

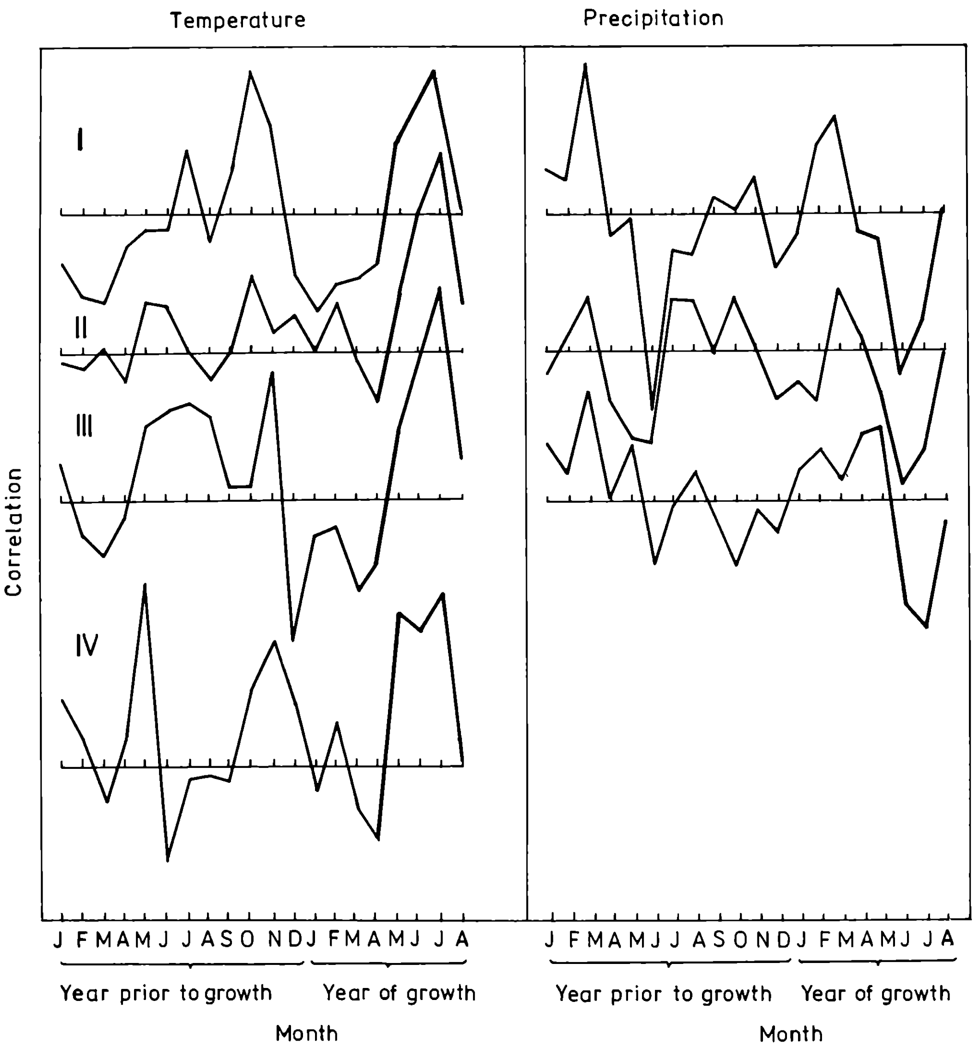

Figure 10. Relation between mean ring-width chronology of Pinus montana - I, Acer pseudoplatanus - II, Pinus cembra - III, Betula carpatica - IV, from Tatra Mts. and average monthly temperatures and total monthly precipitation, expressed by coefficient of correlation.