Source: Heinrich I, Gärtner H, Monbaron M, Schleser G (eds.) (2006) TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 4: Proceedings of the DENDROSYMPOSIUM 2005, April 21st – 23rd 2005, Fribourg, Switzerland. Schriften des Forschungszentrums Jülich, Reihe Umwelt Vol. 61, p. 77 – 83.

# Tree rings and climate in sub-Mediterranean Slovenia

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## Introduction

Not many geographical or other studies in Slovenia discuss correlations between the climate and the growth of trees. The problem of establishing the upper tree- and forest-line was studied by Lovrenčak (1977, 1987), Gams (1977), and Plesnik (1971). Levanič (1996) studied the dendroclimatology of European silver fir on the Dinaric high plateau in central Slovenia, and Ogrin (1989, 1991 and 1998) mainly studied dendroclimatology of the Alpine and the sub-Mediterranean regions in Slovenia.

The Sub-Mediterranean and the Alpine regions are most suitable for dendroclimatological investigations in Slovenia since they have certain limiting conditions for the formation of radial increments. Sub-Mediterranean Slovenia is typified by its deficit in humidity in summer months, which is also partly due to prevailing karstic features of the surface. These conditions are more or less clearly reflected in radial increments of trees, confirmed by the previous studies. Thus, the need for further investigations became evident because a climate signal registered in the width of annual rings is indistinct in many places, or deviates from a general scheme of radial increment formation in similar conditions elsewhere in the world (Aloui, 1978, Berger et al., 1979, Seue, 1973, etc.). The formation of radial increments strongly depends on various stress situations, as well as on the local, also non-climatic conditions which cannot be sufficiently comprised in dendroclimatological methodology.

## Study area

The term 'sub-Mediterranean Slovenia' denotes the south-west region of Slovenia, which lies under the Alpine-Dinaric barrier and opens towards the Adriatic, from which the mitigated Mediterranean influence spreads. The region is composed of flysch and carbonate rocks in which limestone prevails. The climate becomes more severe the further one gets from the sea. Average temperatures in January are higher than 0 °C (by the sea, > 4 °C), and in July, higher than 20 °C. Annual precipitation by the sea is 1000 mm, and 1600 mm in the foothills of the Dinaric barrier. The majority of precipitation falls in autumn, while the smallest amounts fall in winter and summer when droughts are frequent, owing to high temperatures and the karstic surface. Forest vegetation is thermophillic (submediterranean) and low forests prevail, consisting mainly of oriental hornbeam and oaks (pubescent and durmast oak). Besides, non-autochthonous forests of black pine with which the barren karstic areas were afforested also occur frequently.


*Figure 1: Geographical position of the investigated area with marked sampling locations.*

## Material and methods

The trees that were sampled for the investigation grow in different growing conditions. In sub-Mediterranean Slovenia, samples were taken from flysch areas (Bržanija, Brdo, Plasa, Topolovec), and also from karstic areas (Socerb, Petrinje, Lipa-Komen). The locations on flysch have better growing conditions; soil is up to 30 cm deep, loamy and not so dry. Bržanija is slightly different; samples here were taken from a marl slope which is exposed to soil solution. On the marl bedrock of the slope, after the afforestation with black pine a hundred years ago, only 10 cm of soil of poorly weathered pine needles accumulated. The sampled trees from the Kras grow on limestone plateau which are covered with up to 10 cm deep non-continuous rendzina, out of which the parent material sometimes protrudes. Samples of oaks (durmast oak and pubescent oak) were taken at the locations of Brdo, Plasa and Topolovec, and samples of black pine at Bržanija, Plasa, Socerb, Petrinje and Lipa-Komen.

Mature trees, with no visible mechanical or other damage and unobstructed crowns were sampled, growing on rather isolated sites (mainly 10 to 20 trees on each location). Most of the samples were taken by means of increment borer. We bored to the center of the trunk at standard breast height, from two opposite sides, parallel with the terrain contours. Trees were felled only at Brdo, Topolovec, Plasa and Lipa-Komen. Air-dried samples were planed, and the width of tree-rings was measured by means of magnifying lens, with the accuracy of 1/100 mm.

Synchronicity of radial increments was established by means of cross-dating, and as a result of anomalies, 6 samples were excluded from further analysis. In making cross-dating we made use of the so-called leading chronologies. Then followed the dating and standardization by means of which the biological trend of growth was eliminated. Applied was the "corridor method". Local index chronologies were made for each site, and from them, regional chronologies were made for individual tree species.

The tree-ring climate signal for both local and regional chronologies was established by means of correlation. In this process, the 13-month period was made use of, from September of the previous year when the beginning of future increment was formed, to September of the respective vegetation period. Correlations for monthly and seasonal values, for the vegetation period (April - September), and yearly values were calculated separately. Correlations of greater than +0.25, or smaller than - 0.25, were taken as significant. As the source of climatic data, meteorological stations located close to and having similar positions to the sampling locations were used: Kubed (262 m) and Komen na Krasu (289 m).

## Results and discussion

*Local and regional chronologies*

The samples represent all growing conditions of parent material, exposure to sun, and landform features at individual locations. Thus, the average growing conditions of each location are reflected in the local chronologies. Only undamaged and moderately damaged trees were used in making chronologies; the samples of trees with intense decline in increments or missing tree-rings were eliminated. From the samples of sub-Mediterranean Slovenia, four local chronologies for black pine and three for durmast oak were made. The pine chronologies are about 40 years long, mainly comprise the period after the World War II. The oak chronologies are of similar length, with the exception of that from Topolovec, which is almost 100 years long, covering the period 1888 to 1985. The regional chronologies were made for the time for which the climate data were available, so that they are 30 to 40 years long. Thus, the regional chronology for black pine is 38 years long, consisting of the period from 1951 to 1988, and regional chronology for oak is slightly shorter, 31 years, made for the time between 1955 and 1985.

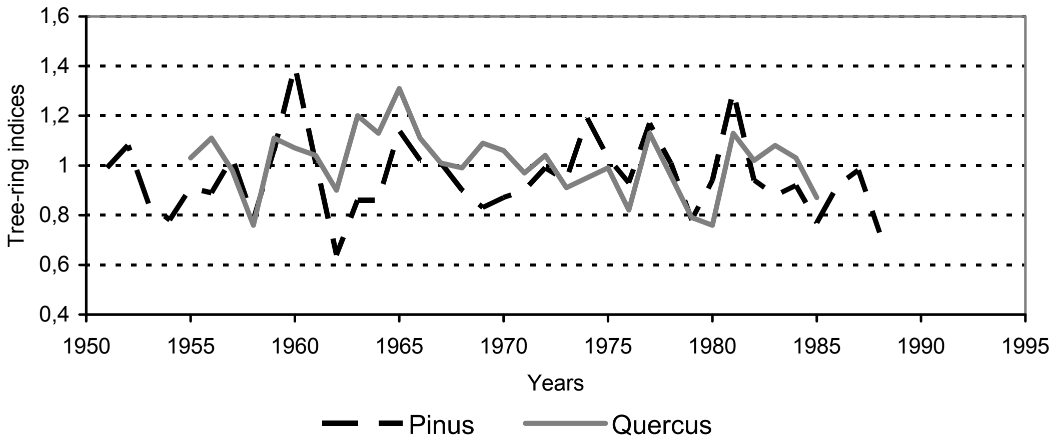


Figure 2: Regional chronologies of tree-rings indexes

*Climate dependence of tree-ring width*

Correlations between the tree-ring widths and temperature and between the tree-ring widths and precipitation were analyzed for individual local chronologies, as well as for the average regional chronologies, separately for each tree species. The whole complexity of relationships between the factors determining radial increments, and the climatic and non-climatic factors are clearly evident in the local chronologies, so that the climate signal registered in the width of tree-rings is often unclear and concealed. The results of regional chronologies evidently show the influence of the so-called mesoclimate, (which is the outcome that we wished to reach with our investigation). These results are discussed below.

*Black pine*

It is evident from the results of correlation analysis (Fig. 3) that during the period of winter dormancy and at the beginning of the vegetation period (spring), the formation of radial increments is being stimulated by above-average temperatures (winter: r = 0.4970; spring: r = 0.2846; March: r = 0.5544). Average winter temperature in the area of sampling locations is approx. 3.5°C, and average summer temperature, 10.8°C, which is, according to Fritts (1976), lower than the optimum temperature for photosynthesis, being 15-20°C for the tree species of moderate climate. However, higher-than-average temperatures in the remaining months and seasons impede the formation of radial increments. The negative impact of the above-average temperatures in summer (r = -0.388) and during the entire vegetation period, from April through September (r = -0.4829) are clear. In the areas where samples were taken, the average summer temperatures are about 20°C, and about 16.5°C in the vegetation period. Higher temperatures in these two periods cause high evapotranspiration, which is "felt" by plants as drought, owing to deficient soil moisture. Potential evapotranspiration in sub-Mediterranean Slovenia is higher than precipitation in July and August, and because of the karstic surface, drought can occur as early as June, and may last until the end of September.

Above-average temperatures in the autumn of the previous vegetation period (September: r = -0.289; October: r = -0.2976; November: r = -0.3535) can be shown to be unfavorable for incremental growth. Firstly, higher autumn temperatures can prolong the formation of tissues which use up the nutrition reserve prepared for the growth in spring; and the second explanation is that higher autumn temperatures postpone the preparation of wood to winter (Fritts, 1976). This increases the sensitivity of tissues to damage caused by cold, and exerts negative influence on the growth in the following season.

A picture of the influence of precipitation is less involved. All statistically relevant correlation coefficients are positive and refer to precipitation in the vegetation period (July: r = 0.2972; September: r = 0.3881; summer: r = 0.3225; vegetation period: r = 0.3713). Also statistically relevant is the correlation coefficient referring to the annual amount of precipitation (r = 0.3413) which means that black pine in sub-Mediterranean Slovenia forms wider tree-rings in the years with above-average precipitation, especially in the vegetation season.

A cause of the need for more abundant precipitation in sub-Mediterranean Slovenia can not be searched in small amounts of precipitation. This need originates in rather high temperatures, and even more in karstic features of the surface and shallow soil cover that can only retain little moisture, which eventually causes drought.

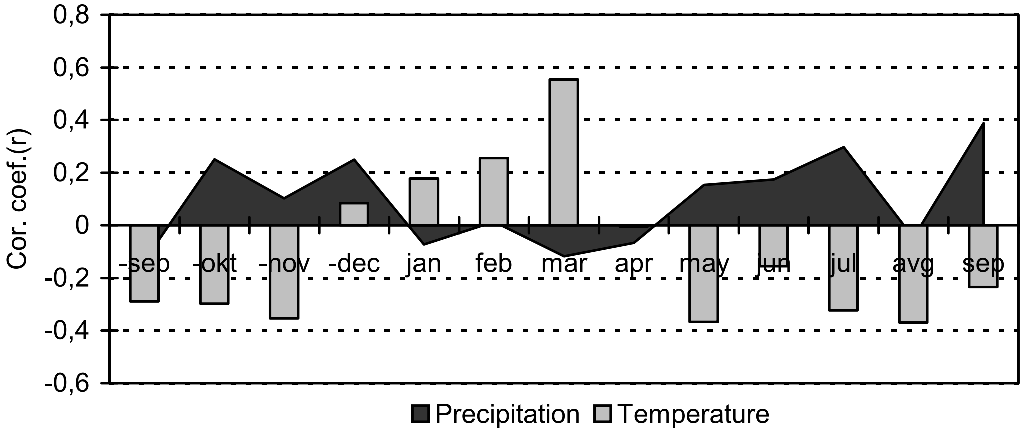


*Figure 3: Correlation coefficients of black pine in sub-Mediterranean Slovenia*

*Oak*

The results for the oak chronologies show similar responsiveness to that of black pine, except that the response to precipitation is stronger at oak. The above-average precipitation is stimulative for the formation of radial increments in all seasons (year: r = 0.2898). If the influence of precipitation is ranked by correlation coefficients, it becomes evident precipitation in the vegetation period (r = 0.6654) and summer (summer: r = 0.5592; July: r = 0.3372; August: r = 0.5002) is most influential on the radial increment. In oak, as in pine, it is important that the above-average precipitation falls during the autumn-winter months of the previous year (October: r = 0.3193; November: r = 0.2207; December: r = 0.2956). Correlation between the precipitation and the width of tree-rings is proportional. The above-average precipitation results in greater soil moisture which reduces the drought stress.

In comparison with black pine, temperature correlations for oak are weaker. The highest values are reached with winter temperatures. Higher temperatures in this season, especially in February, exert negative influence on the formation of radial increments (winter: r = -0.3003; February: r = -0.3371). This is just the opposite of black pine at which higher winter temperatures have positive influence on the formation of radial increments. One of the possible explanations for this correlation is that winter in sub-Mediterranean Slovenia is the season with the smallest precipitation amount, 250-300 mm, and February with only 80 mm is the driest month. Thus, higher temperatures in this season increase evapotranspiration which, together with deficient soil moisture, results in drought stress. According to Fritts (1976) and Pilcher and Gray (1982), higher temperatures can also directly influence the increased respiration which causes that plant consumes a part of its nutrition reserves as early as winter, which is later manifested in form of reduced increment.

In contrast to winter, a warmer spring or an earlier beginning of the vegetation period is manifested in wider tree-rings (March: r = 0.2739; April: r = 0.2865; spring: r = 0.2485). Except for the August temperatures (r = -0.2752), the above-average temperatures in summer do not exert any more significant influence on oak.

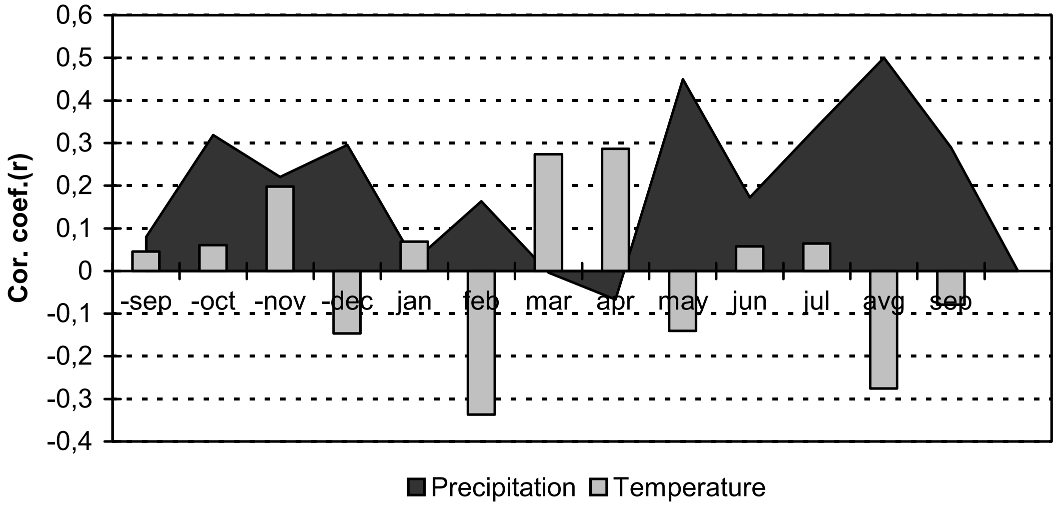


*Figure 4: Correlation coefficients of oak in sub-Mediterranean Slovenia*

**Conclusions**

By means of average regional chronologies which were made from local chronologies within an individual climate type, a climate signal registered in the width of tree-rings can adequately be discovered under the condition that trees are climatically sufficiently sensitive, or an element exists within the climatic complex representing the most favorable conditions for the formation of radial increments. Of the three main climate types in Slovenia, the sub-mediterranean, the mountainous and the moderate-continental (Ogrin, 1996), the climate signal recorded in the width of tree-rings is most easily discernible in the sub-mediterranean and also in the mountainous climates.

In sub-Mediterranean Slovenia, the restricting factor of radial increment formation occurs in a form of drought which is further intensified by karstic surface at certain places. Thus, radial increments of oak and black pine are in positive correlation with precipitation, particularly in the vegetation period, and in negative correlation with higher temperatures in the same period. The importance of precipitation in the vegetation period is more explicit in the case of oak, since as much as 44% of radial increment variance can be assigned to it. The conditions at the end of the previous vegetation season are an important influence on growth (preparation for winter), with a wetter than the average autumn with below average temperatures resulting in the largest subsequent rings. In favorable conditions, pine begins to assimilate as early as the end of winter (February), and responds favorably to a warm winter. A warmer spring is favorable for both the tree species studied.

In comparison with the studies which were made in the areas with true Mediterranean climate, where the precipitation amount is smaller, temperature higher and summer drought more explicit, the statistically relevant correlation coefficients for Slovenia are rather low (most of them up to ±0.4). Also the percentage of variance in radial increment assigned to climate is low. It is slightly higher than 30% for black pine, and 47% for oak. By comparison, Aleppo pine growing in the surroundings of Marseille in southern France, shows as much as 68% of radial increment variance can be accounted for by climate (Munaut, 1982, in: Hughes et al. 1982).

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