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DENDROCLIMATOLOGY OF MOUNTAIN PINE (*PINUS UNCINATA* RAM.) IN THE CENTRAL PLAIN OF SPAIN.

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ABSTRACT

Few dendrochronological studies have been carried out in Spain or Portugal. Mountain pine (*Pinus uncinata* Ram.) may be especially suitable for investigation because of its broad altitudinal range and great age. Samples from a site in the Sierra de Cebollera were prepared and dated using several cross-dating techniques. The dated series were used to develop a ring-width index chronology that was compared with local climate data. Ring-width variability is related to precipitation, but temperature can also be important, indicating a complex climate response. Future studies of this species will be important for dendroclimatology and for study of ecophysiology of subalpine plants in the Mediterranean area.

In Spanien und Portugal wurden nur wenige dendrochronologische Untersuchungen durchgeführt. Die Bergkiefer Pinus uncinata dürfte aufgrund ihres weiten Höhenspektrums und großen Alters für derartige Analysen besonders geeignet sein. Von einem Standort in der Sierra de Cebollera wurden Proben gewonnen und mit Hilfe verschiedener Verfahren synchronisiert. Aus den datierten Jahrringfolgen wurde eine Jahrring-Index-Chronologie erstellt und mit lokalen Klimadaten verglichen. Die Jahrringbreitenstreuung ist mit den Niederschlägen korreliert, doch kann auch die Temperatur von Einfluß sein, so daß eine komplexe Klima-Wachstumsbeziehung vorliegt. Weitere Untersuchungen mit dieser Baumart werden für die Dendroklimatologie und Ökophysiologie subalpiner Pflanzen im Mittelmeerraum von Bedeutung sein.

Peu d'études dendrochronologiques ont été effectuées en Espagne et au Portugal. Le pin de montagne (Pinus uncinata Ram.) peut être spécialement utile en raison de sa grande amplitude altitudinale et de son grand âge. Des échantillons provenant d'un site de la Sierra de Cebollera ont été préparés et datés en utilisant plusieurs techniques d'interdatation. Les séries datées ont servi à développer une chronologie d'indices qui a été comparée avec le climat local. La variabilité des épaisseurs de cernes est liée aux précipitations, mais les températures peuvent aussi être importantes, indiquant une réponse climatique complexe. Des études futures portant sur cette espèce seront importantes pour la dendroclimatologie et pour les études écophysiologiques de plantes subalpines dans la région méditerranéenne.

INTRODUCTION

During the last decade many dendrochronological studies have been carried out for large areas around the world. Although there are many chronologies developed for the Central-European area and for northern Europe (Eckstein 1972), studies in the southern part and especially in the Mediterranean area are scarce (Serre 1978). The Iberian Peninsula is a very characteristic area within the Mediterranean region, where the natural vegetation, although present only in mountainous areas and at great altitude (in many cases over 2000m), still reveals its Mediterranean influence. Studies on dendrochronology in Iberia have been very few (Creus and Puigdefábregas 1976; Tomás 1982; Gracia and Génova 1982; Génova and Gracia 1984).

For some years, a research group of the Department of Ecology, University of Barcelona, has been analysing the series of growth rings of mountain pine, *Pinus uncinata* Ram., at different sites. This paper summarizes the results obtained for a population located in a marginal area of its biogeographical distribution, centered on the Sierra de la Cebollera (Soria) in the Central Plain of Spain (Figure 1).

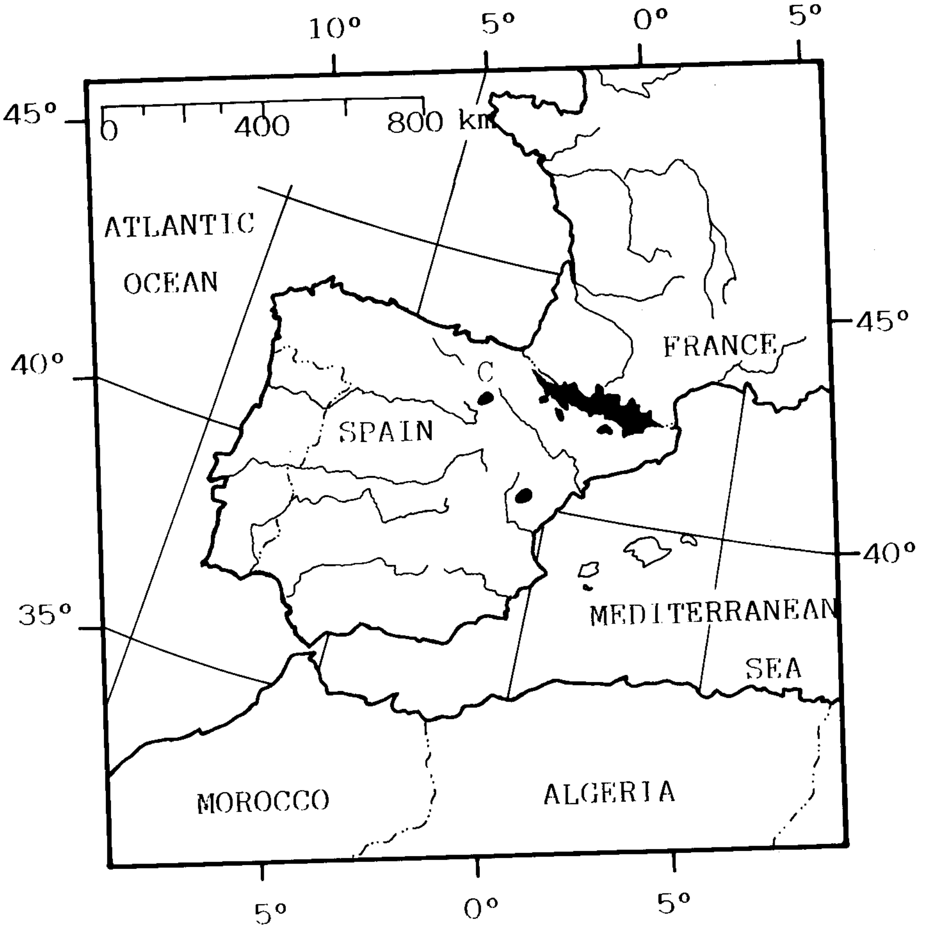

Figure 1. Location of study area (C) and the distribution of *Pinus uncinata* in the Iberian Peninsula (shaded).

Mountain pine is a species limited to the highest altitudinal areas of Iberian mountain systems. Its distribution varies from 1600 to 2700 m. At lower altitudes it competes with the Scots pine, *Pinus silvestris* L., of widespread European distribution. The mountain pine is quite similar in many aspects to the mountain pine of the Alps, *Pinus mugo* Turra. Although the most densely forested areas are located in the Pyrenees, it occurs in other mountain ranges as relicts that are apparently related to the backward and forward movements of vegetation during the last glacial periods (Cantegrel 1984).

This species presents characteristics which make it particularly appropriate for dendrochronological studies, such as its distribution and the fact that some individuals may reach ages of more than 600 years (Ceballos and Ruiz del Castillo 1971).

MATERIAL AND METHODS

In autumn 1983, 23 samples were taken from 11 different trees. Cores samples were extracted by the standard coring instruments. The sampled trees were chosen, trying to secure homogeneity in all environmental conditions, from those trees with largest diameters at breast height.

Once in the laboratory, the cores were polished with sandpaper of progressively finer grain. They were dyed, with picrofucsin, so as to accentuate the differences between the earlywood and latewood. This facilitates the measurements of growth rings by clearly defining their annual limits. Of the initial 23, some cores with anomalies were discarded, and a total of 17 cores from 9 different trees remained for analysis.

The standardization of the samples was carried out following the usual methods (Fritts 1976). The data were indexed using a negative exponential function:

$$Y(t) = a \exp(-bt) \tag{1}$$

Where Y(t) is the expected growth in a given year t, and a and b are different parameters depending upon the slope of the curve selected to fit the data. This function has been used by many authors in previous studies of conifers (Fritts 1965, 1966; Creus and Puigdefábregas 1976; Berger *et al.* 1979). In those cases in which this adjustment was not possible, a linear function with different slopes was used.

Crossdating was carried out using three different types of analysis, now regarded as classic in the analysis of dendrochronological series: (1) visual markers and repeated readings; (2) the automatic skeleton plot technique (Cropper 1979); (3) a test of parallel variation "Gleichlaufigkeit" (Schweingruber *et al.* 1978; Baillie 1982; Lamarche & Hirschboeck 1984).

The climatic data used in the calibration were taken from an observatory located approximately 20 km from the sampling point. A 22-year data series of monthly mean temperatures and monthly total precipitation was available. So short a climatic series implies important methodological problems, but since observatories with longer data are located in clearly different environments, it was preferable to use this one. The climatic variables have been taken in 14-month periods, from June of the previous year to July of the current year of growth. This 14 month division may help in the interpretation of the results through comparison with studies carried out in other similar biogeographic areas. All the climatic data have been normalized so that all may have the same weight in the analysis. The index series was transformed logarithmically, for the purpose of getting a data distribution closer to the normal distribution.

A stepwise multiple regression analysis was performed to find the climatic response function of the tree-ring chronology. This type of analysis, despite the difficulties (Fritts 1976), has been successful in many situations (Serre *et al.* 1966; Berger *et al.* 1979). One of the problems in this analysis is that all the climatic variables considered are strongly interrelated. In order to choose a smaller group of variables, the analysis was carried out using, in a first approximation, all monthly data (14 precipitation and

14 temperature variables). All those of greater weight are entered in successive steps, until a prefixed limit was reached after which they are removed, in a stepwise fashion. This form of analysis enables the detection of possible redundancies and synergic effects. The criteria used for the inclusion or exclusion of new variables was done using a statistic (F test) with a previously defined tolerance. It is recognized that some caution must be exercised in interpretation of results based on screening such a large number of variables, given the short length of the observational series (Berger *et al.* 1979).

RESULTS

In Table 1, the values of the standard statistics calculated for the 17 analyzed cores are given. The years covered reach a total of 322, corresponding to the age of the oldest core analyzed. the mean tree-ring width is around one mm. The maximum width is of 3.93 mm, and the minimum is 0.05 mm. The average mean sensitivity is 0.182, a fairly low value but comparable to that observed in other species in ecologically similar sites or comparable geographic locations (Creus and Puigdefábregas 1976; Serre 1978; Brubaker 1982). The correlation coefficients between each core and the average site chronology are also given in this table. The level of significance in all cases is over 99%. Table 1 also summarizes the values obtained for the "Gleichlaufigkeit" and the correlation coefficients between cores taken at different orientations within the same tree. In both analysis the confidence limits exceed 99%. Table 2 presents complementary information for the "Gleichlaufigkeit." It is interesting to note that with a lag of 1 or 2 years, the significance of the analysis is lost in all cases. The mean site chronology, which results from averaging all the analyzed cores, is presented in Figure 2.

DENDROCLIMATOLOGICAL ANALYSIS

The stepwise multiple regression analysis show that of the initial 28 climatic variables, a reduced group of 8 explains 95% of the total variance in ring width. This is made up of total monthly precipitation for June, July, August and November, and mean monthly temperatures of June, November and December during the year prior to growth and total monthly precipitation of March of the current year of growth. It is noteworthy that of the 8 variables, 7 are for the year previous to growth (Figure 3). This interesting result may be partly related to the intercorrelation of the monthly climatic variables, which should be kept in mind during the following discussion. The regression coefficients of 3 of these variables did not significantly differ from zero, and they were removed from the analysis. The group of climatic variables was thus reduced to 5, and explained 92% of total variance ($R^2 = 0.924$). The regression equation is as follows:

$$\mathrm{Lind}(t) = 0.178 + 0.049\ \mathrm{Pag}(t-1) - 0.058\ \mathrm{Pn}(t-1) - 0.026\ \mathrm{Pm}(t) - 0.039\ \mathrm{Tj}(t-1) + 0.054\ \mathrm{Tn}(t-1) \tag{2}$$

where Lind is the ring width index expressed as logarithms, Pag, Pn and Pm are total monthly precipitation for August, November and March respectively, and Tj, Tn are the mean temperatures for June and November, and t denotes the year.

The pattern found is logically related to the climatic conditions which exist in

Table 1. *Pinus uncinata* sample statistics. MRW, Mean ring width. SD, Standard deviation. MS, Mean sensitivity. R(a), Correlation of each core with the average index series. R(b), Correlation within trees. GL, "Gleichlaufigkeit" values within trees.

CORE	Number of Years	MRW (mm)	SD	MS	R(a)	R(b)	GL
1-CB-SE	96	1.356	0.377	0.211	0.754**	0.625**	76.27**
1-CB-N	64	2.568	0.255	0.168	0.530**		
2-CB-SW	310	0.533	0.620	0.262	0.844**	0.883**	60.42**
2-CB-NE	272	0.734	0.680	0.200	0.805**		
4-CB-SE	108	1.041	0.240	0.160	0.636**	0.515**	75.49**
4-CB-NW	113	1.203	0.193	0.145	0.430**		
5-CB-S	242	0.549	0.369	0.172			
6-CB-SE	209	0.579	0.602	0.185	0.672**	0.523**	77.72**
6-CB-NW	203	0.497	0.393	0.180	0.748**		
7-CB-N	119	1.198	0.269	0.186			
8-CB-SW	113	0.642	0.247	0.138	0.693**	0.606**	79.38**
8-CB-NW	248	0.656	0.353	0.148	0.518**		
9-CB-W	134	0.806	0.401	0.177	0.712**	0.366**	75.00**
9-CB-E	121	1.242	0.223	0.166	0.465**	0.760**	83.91**
9-CB-E2	90	0.818	0.263	0.178	0.602**		
10-CB-NE	322	0.422	0.767	0.187	0.899**	0.817**	72.18**
10-CB-NW	274	0.533	0.529	0.198	0.846**		

**Significant at 99% confidence level

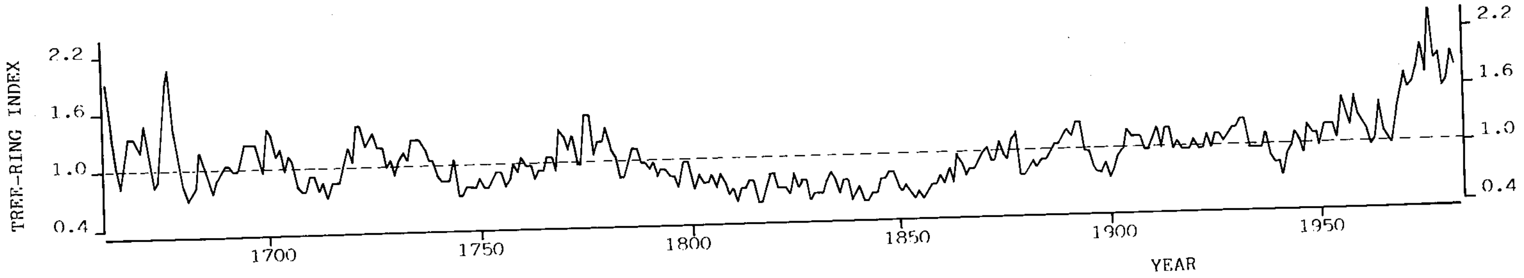

Figure 2. *Pinus uncinata* chronology based on 17 radii from 9 trees.

Table 2. "Gleichlaufigkeit" values of each tree with the average index series (Mean), and with the series lagged 1 year (a) and 2 years (b).

	1-CB	2-CB	4-CB	5-CB	6-CB	7-CB	8-CB	9-CB	10-CB
MEAN	67.39**	70.36**	75.00**	62.87**	78.64**	59.13*	72.10**	79.70**	72.33**
MEAN(a)	42.86°	43.14°	48.65°		49.76°		45.26°	43.94°	42.27°
MEAN(b)	47.78°	51.48°	52.73°		42.16°		47.19°	44.27°	49.68°

**confidence level ≥ 99%
*confidence level ≥ 95%
°confidence level < 95%

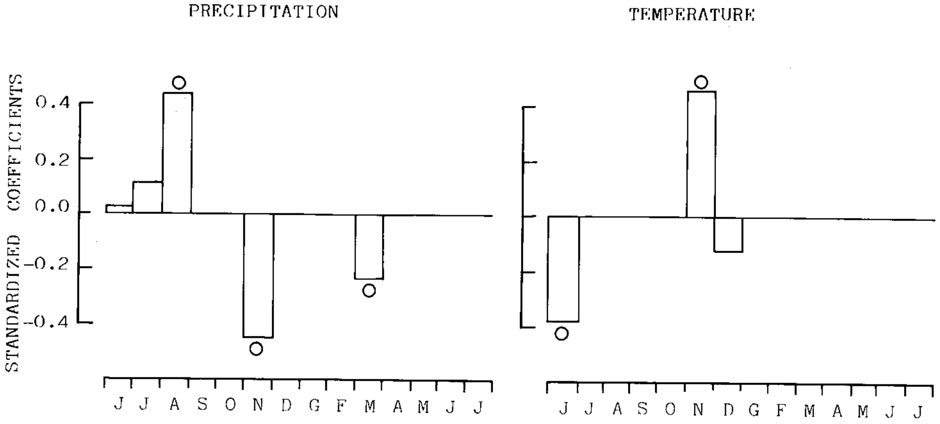

Figure 3. Results of stepwise multiple regression analysis at step 8. Five variables are significant at the 99% level of confidence (o), explaining 92.4% of the variance. G is January.

areas of high altitude: high light intensity, low temperatures and low CO^2 partial pressure (Tranquillini 1964).

Precipitation seems to affect the ring width in three different periods: summer directly, and in autumn and spring with an inverse relationship. In the summer period the plant may experience serious water deficits, typical of Mediterranean ecosystems. On the other hand a period of heavy rainfall during the month of August will be beneficial for the plant, which, as it does not lack water, can transpire normally and thus maintain high photosynthetic rates, and consequently a greater wood production. The fact that high precipitation values have a negative effect for the initial growth period (spring), as well as for the final one (autumn), is understandable, considering the relationship between rainfall and radiation. It is well established that the beginning of the vegetative period and the end of dormancy are closely related to the day length. This effect is especially apparent in species which are growing at high altitudes (Kozlowski 1971; Creber and Chaloner 1984) or latitudes (Vaartaja 1962; Häbjϕrg 1978). Clouds associated with high precipitation reduce the radiation that reaches the plant, with an inhibitory effect, through hormonal response, on active growth. The surprising importance of such an early month as March in the physiological response of the tree, must be reconsidered in the light of the Mediterranean conditions. This aspect has been clearly manifest in other dendrochronological studies carried out for this area (Serre 1978; Gracia and Gênova 1982).

The pattern of the temperature response also reveals the same tendencies: a negative effect in June and a positive one in November. The outline is inverse to that of the precipitation: high temperatures in the summer period can result in a considerable water loss because of high transpiration, which is not compensated by a sufficient water reserve; this causes inmediate closure of the stomata and the consequent photosynthetic stop in the plant. On the contrary, high temperatures at the end of the growth period result in a prolongation of the vegetative period, and therefore a wide ring results.

All seems to indicate that for the analyzed trees, precipitation is more important than temperature. The studied individuals are located at the highest point of the mountain ridge, and are subjected to strong winds and thin soil, which implies serious problems of water availability. At the same time, during the period of greater precipitation (in the months of November to February), low temperatures, reduce the availability of water to the plant. Some authors suggest that in this area there may be snow up to 250 days a year (Fontana Tarrats, unpublished report, 1977).

In Figure 2, it can be seen that the index series tend to increase during the last 25 years. The rainfall values for the 20 year period studied reveal a clear descending trend for November precipitation. The values varied from an average of 200 mm to approximately 75 mm in recent years. The same tendency is observed for March rainfall, which decreases from 200 mm to around 50 mm. For August total precipitation the observed trend is inverse, that is in the last 20 years there is a tendency toward higher rainfall (Figure 4).

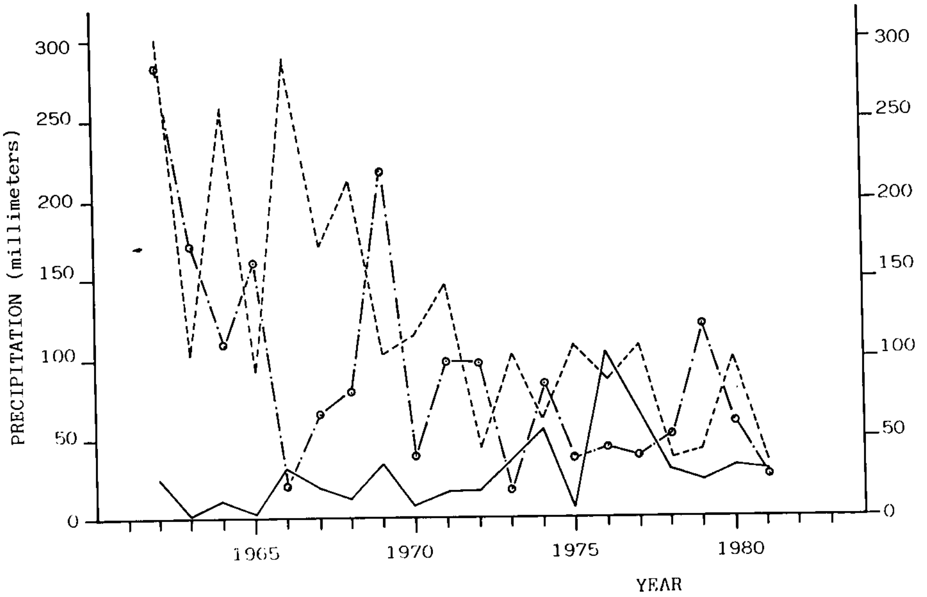

Figure 4. Monthly precipitation of November (— — — —) and August (————) for the year prior to growth and of March (—·——·—) for the year of growth in the study area.

To verify the local climatic data, we also studied the climatic tendencies reported by the 4 nearest weather stations. All these were located inside a maximum radius of 25 km. Even though these observatories are very close to each other, they present significant geographical differences. However close inspection of all the climatic data together shows the same trend for the March, August and November precipitations.

On the other hand the reason for the increase in the tree-ring indices (Figure 2) for the past 150 years is more complex. It is possible that subalpine vegetation, and especially conifers growing at the upper tree-line, at high altitudes, exhibit an increment in growth as a direct response to increasing concentrations of atmospheric CO^2, as was reported by LaMarche *et al.* (1984). Intervals or decreased growth around 1750 and from 1800-1860 may reflect adverse conditions associated with the latter part of the "Little Ice Age."

CONCLUSIONS

The chronology presented here constitutes the first results of the work that currently is being done on *Pinus uncinata* Ram. in some areas of Spain. This species has proven to be potentially very important for future development. The similarities between this species and the mountain pine of the Alps *Pinus mugo* Turra will give opportunities for comparison and will contribute to the understanding of ecophysiology of alpine plants in the Mediterranean area.

Dendroclimatic analysis seems to indicate that total monthly precipitation is more important than monthly mean temperatures. Of the 28 initial climatic variables, 5 can explain 92% of the total variance due to growth. Four of these are for the year previous to the growth ring formation. High precipitation for March and November has a negative effect on plant growth. On the other hand high precipitation during August has a beneficial one. This physiological response must be reconsidered in the light of the Mediterranean conditions. The pattern of temperatures once more reveals the same tendencies, but inversely: a negative effect in June and a beneficial one in November. Everything seems to indicate that high precipitation in March and November, as well as above average temperatures in June, results in the formation of a narrow ring. The opposite pattern is also true.

The rainfall values for the 20 year period studied, reveal a clear descending tendency for November and March, and an increasing one for August. This agrees with the trend exhibited by the tree-ring index series.

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