Pirineos, 143-144: 55 a 70, JACA; 1994

RELATIONSHIPS BETWEEN MOUNTAIN PINE AND CLIMATE IN THE FRENCH PYRENEES (FONT-ROMEU) STUDIED USING THE RADIODENSITOMETRICAL METHOD

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ABSTRACT.- A radiodensitometrical study was carried out on 46 Pinus uncinata (Ramond) in Font-Romeu (French Pyrenees). Correlation functions with monthly climatical data were calculated using separately the ring-widths, the earlywood and the latewood densities. The Mountain Pine shows narrow rings (1.5 mm) and a high sensitivity to climate (M.S. = 0.221), but it does not seem to suffer from drought despite the dryness of the climate (788 mm rainfall per year). This species is more sensitive to temperature than to precipitation, since temperature governs latewood formation. A hot spring and a mild autumn with maximum temperatures above threshold levels will extend the growing period. A warm autumn also increases the latewood density, whereas cold nights during the previous year's autumn are unfavourable to growth because they may affect the cambium and bud initiations.

RESUMEN.- Se ha llevado a cabo un trabajo densitométrico sobre 46 Pinus uncinata (Ramond) en Font-Romeu (Cerdaña francesa). Las funciones de correlación con el clima han sido calculadas sucesivamente con el espesor de los anillos de crecimiento, la densidad de la madera temprana y de la madera tardía. Esta especie produce anillos de crecimiento delgados (1.5 mm) y presenta una elevada sensibilidad con el clima (S.M. = 0.221) pero no parece afectada por la falta de lluvia aunque el clima es más xérico (788 mm/año). La madera tardía parece muy sensible a las temperaturas. Una primavera cálida ejerce un efecto favorable y un otoño suave con temperaturas máximas superiores a límites críticos permite continuar su desarollo. De la misma manera un otoño caliente aumenta la densidad de la madera tardía aunque las noches frías durante el otoño precedente son desfavorables para el crecimiento porque pueden afectar al inicio de las yemas y del cambium.

RÉSUMÉ.-Une étude radiodensitométrique de 46 Pinus uncinata (Ramond) a été réalisée à Font-Romeu (Pyrénées Françaises). Les fonctions de corrélation avec le climat ont été calculées successivement avec les largeurs de cernes, les densités du bois initial et final. Cette espèce forme ici des cernes étroits (1.5 mm) et présente une forte sensibilité au climat (M.S. = 0.221), mais ne semble

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pas être affectée par le manque de pluie malgré la sècheresse du climat (788 mm de pluie par an). Le Pin à crochets est davantage sensible aux températures par l'intermédiare du bois final, et préfère un printemps chaud ainsi qu'un automne doux avec des températures maximum supérieures à des seuils critiques afin de prolonger sa période de croissance. Un automne chaud augmente également la densité du bois final, tandis que des nuits froides durant l'automne précédent sont défavorables a la croissance, car elles peuvent affecter l'initiation des bourgeons et du cambium.

Key-words: *Dendroclimatology, Mountain Pine (Pinus uncinata Ramond), Pyrenees, Radiodensitometry, Growth.*

1. Introduction

Several studies have been carried out on the Mountain Pine (*Pinus uncinata* Ramond) in the Pyrenees (Puig, 1982,Cantegrel, 1983, Probst & Rouane, 1984). The dendroclimatological method was used by Spanish authors on this species (Creus & Puigdefábregas, 1976, Génova Fernández, 1987, Ruiz-Flaño, 1988, Gutiérrez, 1989, 1991). However,all these studies were based on ring-width measurements. The radiodensitometrical method for measuring the wood density may provide more accurate results. This is because the density is linked to both the number and the size of the wood cells and to the thickness of the cell walls. Thus, it is a good factor to enable a study of the growth. Moreover, it permits separate analysis of the influence of the climate on the earlywood formed during the spring, and on the latewood formed during the summer months. Our purpose in this study is to characterise the influence of the monthly climate on the formation of wood, that is assumed to be particularly sensitive to climate in this dry region.

2. Materials and methods

A forest of Mountain Pine was studied close to Font-Romeu in the Pyrenees, on the South facing slope of the granitic French Cerdagne. The altitude ranges from 1780 m to 2120 metres with an average slope of 15 %. The heights and diameters of 46 Mountain Pines were measured, and one core per tree was taken at breast height using a Pressler borer. The cores were X-rayed and the wood densities of each ring were measured with a densitometer, using the radiodensitometrical method (Polge, 1970, Keller & Millier, 1970). This work was done in R. Keller's laboratory (CNRF, Nancy). The mean sensitivity (M.S.) and the four first autocorrelation coefficients (R1 - R4) were calculated for each core, before calculating the averages for all the trees <MS> and <Ri>. Master chronologies were obtained after cross-dating the individual series by averaging all the rings available for each year (Fritts, 1976). Growth indices were calculated by using moving averages with 7 coefficients. Then the correlation coefficients between the indices of the master chronologies of rings and the monthly climatic data were calculated (Blasing, Salomon & Duvick, 1984) Thus correlation functions with the climate

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were obtained. Records of precipitation data, mean temperature, minimum and maximum temperature were available from 1950 in the Font-Romeu meteorological station in Osséja (I.S.G.M.P., J.F. Tricaud), the number of hours of sunshine has only been available since 1971. The former station is situated close to the studied site (at approximately 1 km and at an altitude of 1710 m) and the latter is 3 km from the forest. The linear correlation coefficients that are significant at the level 0.90 were drawn in black on the figures. Moreover, those that are significant at the levels 0.95, 0.975, 0.99 and 0.995 are respectively shown by stars (*) of four increasing sizes. Ring widths, minimum densities and maximum densities were used separately for the calculations.

3. Discussion and results

3.1. *The climate in Font-Romeu*

The weather in Font-Romeu is particularly dry and sunny. During the sunniest month (July), 296 hours of sunshine are measured, and on average they are 2488 hours of sunshine per year. Yearly average precipitation is only 788 mm rainfall per year, and yearly mean temperature is 6.1 °C (with T_{min} = 1.5 °C and T_{max} = 10.6 °C) (Figure 1). However, since August is the most rainy month of the year this may compensate for the high solar radiation in summer

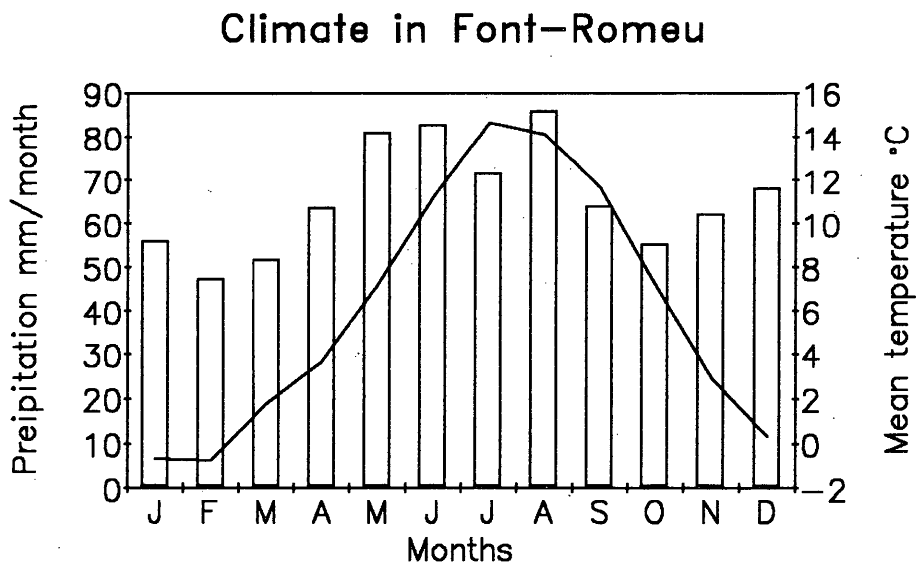

Figure 1.

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3.2. *Tree measurements, ring sizes and wood densities*

Tree heights range from 7 to 17 metres, and the diameters from 10 to 52 cm. On average, the studied Pines measure 13 m tall,their mean diameter is 37.5 cm and they are 118 years old.

Most of the rings are quite narrow, since the mean ring width is only 1.50 + 0.62 mm (average + root mean square). The distribution curve is unimodal with a regular shape (Figure 2a) and the most frequent measured value is 1.25 mm. The cumulated frequencies show that small rings are numerous, since 15% of the ring widths are less than 0.60 mm and 35 % are below 1.00 mm. On the contrary, 35 % are above 1.50 mm, 15 % are above 2.10 mm and only 5 % exceeded 2.80 mm.

The average minimum density is 292 ± 41 g/dm^3, and the average maximum density is 683 + 104 g/dm^3 (Figure 2b). The latter results show a greater variance due to an increased importance of the climate in summer than in spring, since this is the most critical period. However, the variation coefficients of both minimum and maximum densities are similar, respectively 14 and 15 %. Their repartition curves are more irregular than for the ring widths. This may be due to environmental differences amongst the trees.

3.3. *Mean sensitivity and autocorrelation*

The mean sensitivities were calculated for 46 cores. The individual M.S. for the ring-widths range from 0.129 to 0.305, with an average value of <MS> = 0.221. Consequently, this value is higher than the results obtained for the same species in the Spanish Pyrenees, in Marranges (MS = 0.189) or in Viella (MS from 0.174 to 0.222) located on granitic soil and on south facing slopes (Génova Fernández, 1987). Our results are also higher than those values obtained in the Iberian system or in the Aragon Pyrenees,that range from 0.187 to 0.201 (Ruiz-Flaño, 1988).

The mean sensitivities of the *minimum densities* range from 0.063 to 0.199, with an average value of <MS> = 0.108. Those of the *maximum densities* range from 0.051 to 0.186, with an average of 0.123. Such values are high compared to those obtained for *Pinus sylvestris* (Huber, 1976). The mean sensitivity value of the minimum density is weakly linked with those of the maximum density, since the linear correlation coefficient between them equals R = 0.053 (Figure 3a). Such a result means that the earlywood and the latewood of a tree show different sensitivities to climate, such that they may react differently to climate. Moreover, latewood is more sensitive to the climate than earlywood, since it is formed during the summer when thermal stress and dryness may occur, during a more critical period. The mean sensitivities of the ring widths increases as the ring widths decrease (R= -0.238). Similarly, the M.S. of both the minimum densities and the maximum densities increase as the densities are reduced (with respectively R=-0.248

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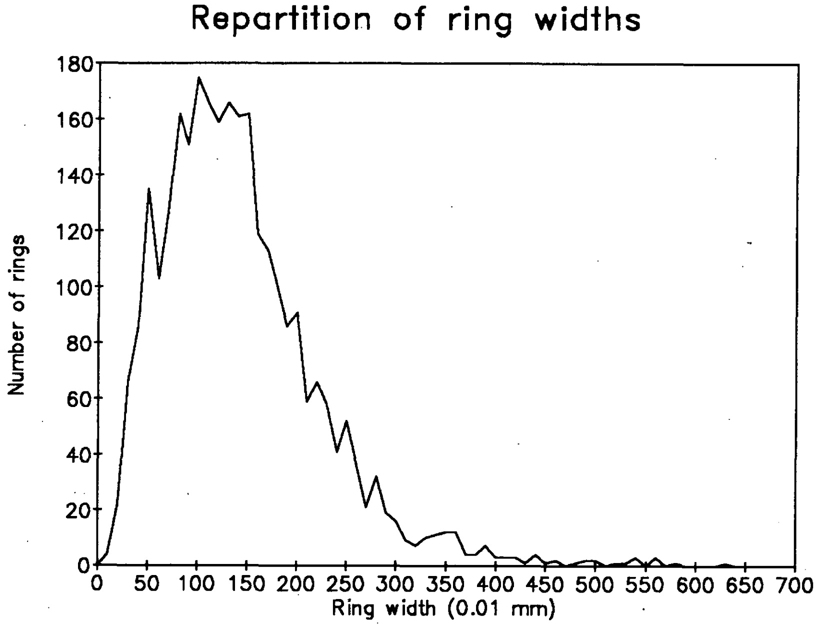

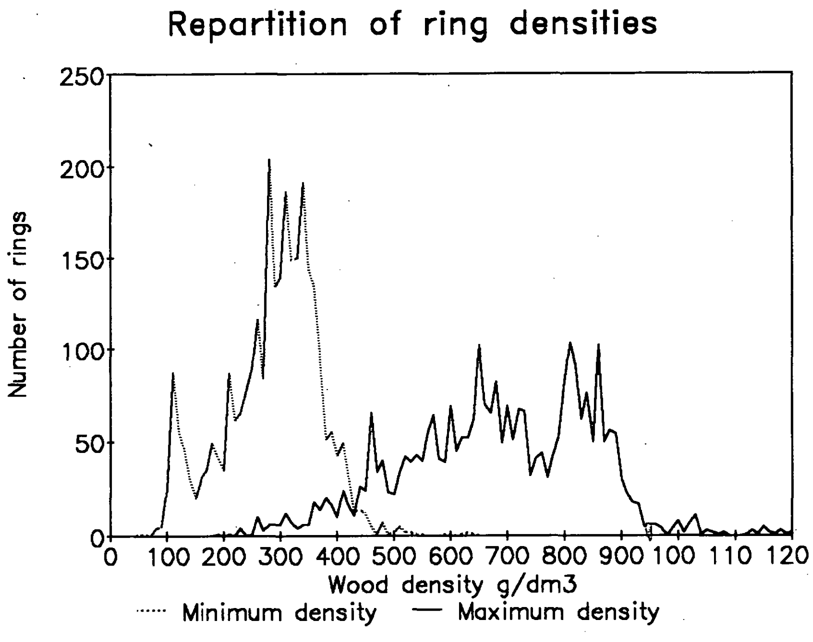

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and R=0.148). Trees with narrow rings and a wood of low density are consequently the most sensitive to climate.

The first order autocorrelation coefficient (R1) for the *rinq widths* averages 0.714 in Font-Romeu (Figure 3b). This factor measures the influence of the year before ring formation. In comparison, higher values for the same species ranging from 0.741 to 0.912 were obtained In the Spanish Pyrenees (Génova Fernández, 1987). These results indicate that the Mountain Pine in Font-Romeu is more sensitive to the climate of the current year and less dependant on the climate during the previous year. It consequently shows a lower inertia and appears to be more opportunistic. Thus, this species provides interesting results for dendroclimatological analysis. The coefficients R_k decrease rapidly as the number of years k increases, but the autocorrelation for the ring widths remains high for at least 10 years, as observed in Coronas (Benasque Valley) (Ruiz Flaño, 1988). However, the climate more than 6 years before ring formation plays a negligible role. Moreover, the autocorrelation coefficients calculated for the densities are less than those of the ring widths, showing that the wood density is dependant on the climate of the current year and weakly linked to the climate the preceding years. Thus, for the minimum densities R_1 equals 0.396 and for the maximum densities R_1 equals 0.418. Consequently, the response to climate is easier to analyse for wood densities compared to ring widths, since the long term influences are reduced. Furthermore, the Rl values decrease more rapidly for the maximum densities, since they are less dependant on long term influences, in comparison to minimum densities that are more influenced by the reserves formed by the Pines the years before.

3.4. *Master chronologies and cross-dating coefficients*

Three master chronologies were calculated with N=46 cores, for the ring widths, for the minimum and for the maximum densities. Their mean sensitivity (MS_{Chr}) is divided by the average mean sensitivity <MS> of the individual cores to obtain the cross-dating coefficient R_d. This coefficient equals 0 if all of the cores react differently to the climatic fluctuations, and it is close to 1 if the variations of the rings characteristics react similarly.

Pinus uncinata	MSchr	<MS>	Rd	Rd.√N	HUBER
Ring widths	0.1289	0.221	0.583	3.96	3.19
Minimum density	0.0440	0.108	0.408	2.77	2.88
Maximum density	0.0657	0.123	0.534	3.62	3.68

The cross-dating coefficients (R_d) are sufficiently high, demonstrating that the cross-dating of individual cores was carried out efficiently. Furthermore,

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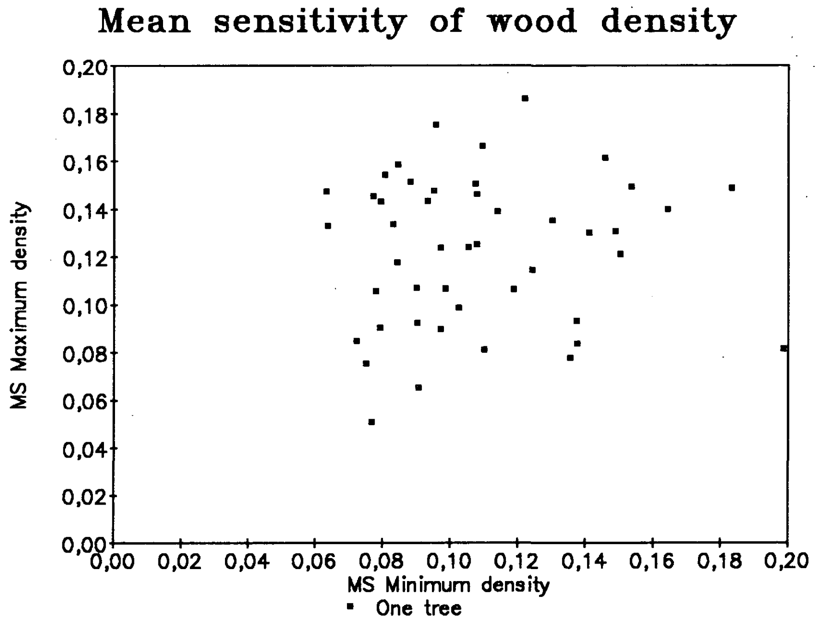

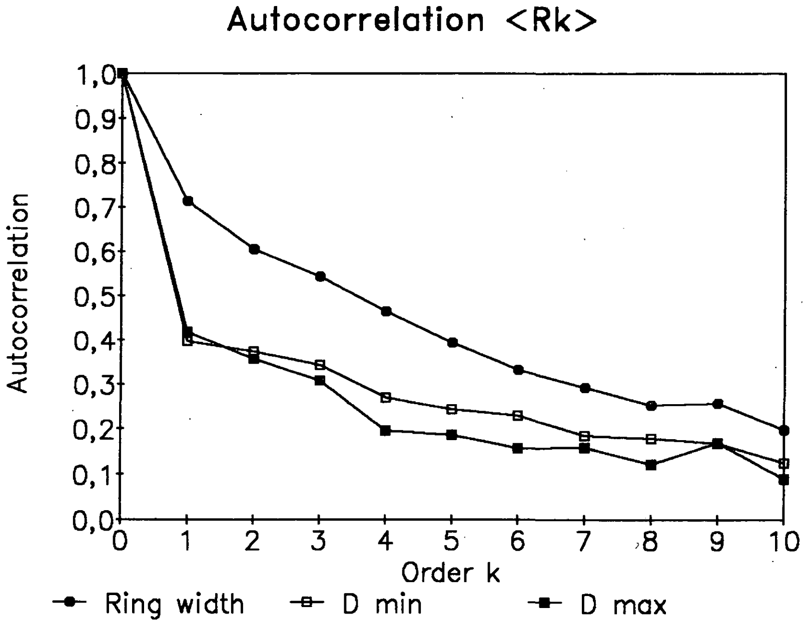

Figure 3.

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our standardised results for *Pinus uncinata* (Rd multiplied by N) are very close to those obtained by HUBER for *Pinus sylvestris* with N=25 cores [HUBER, 1976]. Consequently, for both species the yearly variations among trees in a forest of ring sizes and densities show a good synchronism.

3.5. *Wood density and ring widths*

The average ring widths were calculated for each core and results have shown that they are negatively linked to the minimum densities and particularly to the maximum densities of the same cores (R = -0.154 and R = -0.309 respectively). On the contrary, both maximum and minimum densities are strongly correlated (R=+0.763). This indicates that trees with dense earlywood usually form dense latewood as well, and form also narrow rings. Thus, the Pines that grow slowly form denser wood, since wood density is due to small tracheids with large walls.

3.6. Influence of Precipitation.

Surprisingly, precipitation during the vegetative period does not cause an increase in ring size, despite dry weather in Font-Romeu (Figure 4a). There is however sufficient rainfall for growth in the summer since they are 83 mm of rainfall in June and 86 mm of rainfall in August. Furthermore, these months are the two wettest of the year. Moreover, low temperatures at high altitudes compensate for low average yearly precipitation. Consequently the Mountain Pine is able to grow here with only small amounts of water. However, the Pine needs a dry *May (n)* to start growth of the current year (n). Growth is also favoured by summer rainfall of the previous year (n-1), in *July (n-1)*.

Minimum density is only slightly linked to precipitation level since earlywood that is formed during the spring uses the metabolitic reserves of the previous year, and because the soil is generally wet enough at this stage after the melting of the winter snow (Figure 4b).

On the contrary, the **maximum density** is strongly dependant on precipitation because latewood is formed during the summer when the soil is drier (Figure 4c). High rainfall throughout one year of ring formation reduces the maximum density, because such weather results in the formation of larger cells. However this phenomenon is widespread and weak. Rainfall between *May (n-1)* and *July (n-1)* prevents the tree from suffering a water stress during the preceding year, and permits the formation of more metabolitic reserves, that enable the maximum density to increase in the following year. In conclusion, *Pinus uncinata* appears to withstand dryness in Font-Romeu, therefore low rainfall is not a limiting factor, although this factor does influence the latewood density.

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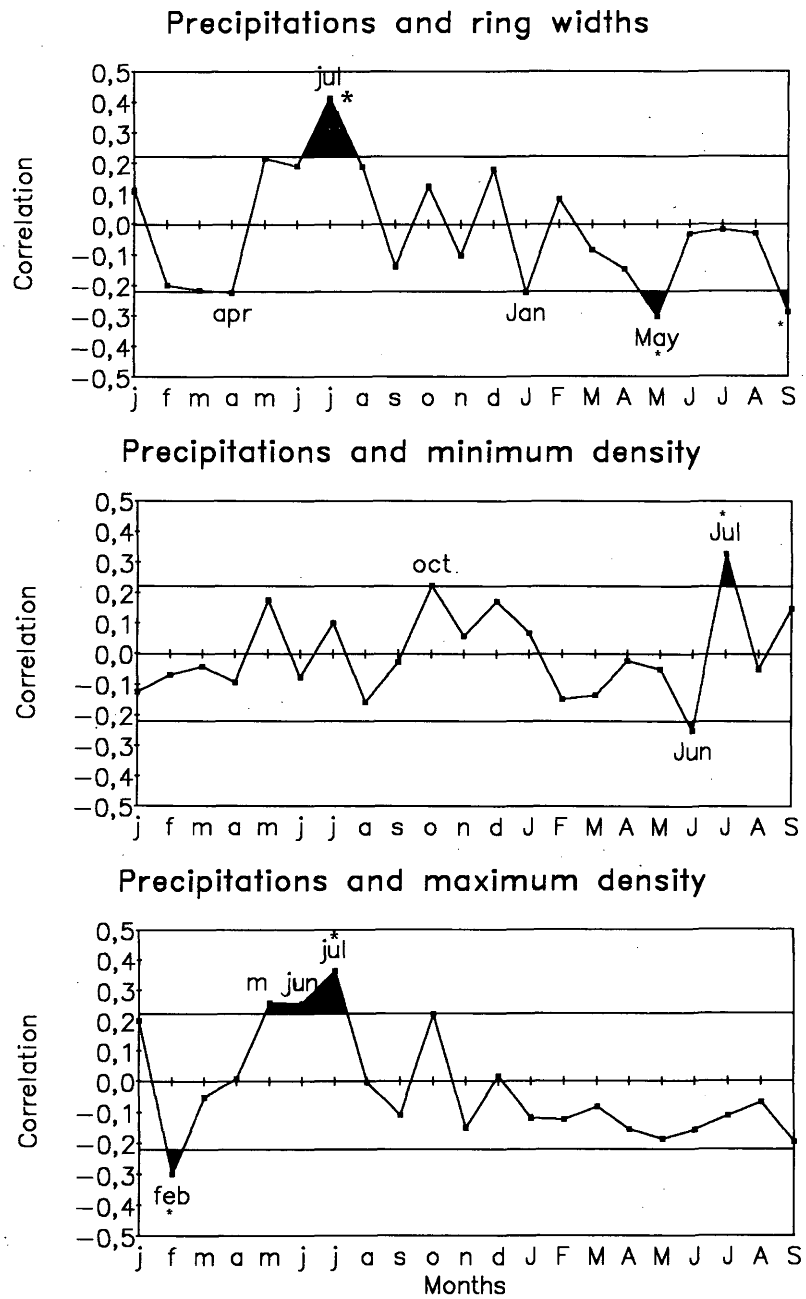

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3.7. *Influence of mean temperature*

The mean temperature obviously plays a more important role than does the rainfall in Font-Romeu. During the present year, the Pines will form larger rings when the mean spring temperatures are high in *April (n)* and *May (n).* This is because it activates the growth (Figure 5a). Similarly, rings are larger if *August (n)* and *September (n)* are hot, probably because it enables an extended growing period. Both these results indicate that hot temperatures at the begining and at the end of the growing period may extend the growth. Quite similar results were obtained for the influence of the temperature on the Mountain Pine in the Aragon Pyrenees (Ruiz-Flaño, 1988). The growing period is extended in Font-Romeu because the mean temperature is 14.1ºC in August, 11.6 °C in September and 7.1 °C in October. It enables the Pines to grow during the autumn. This is contrary to the French Alps where the growth period of this species normally ends at the end of July (Rolland, 1993). A similar long growing period was observed in the Spanish Pyrenees by other authors (Ruiz-Flaño, 1988).

During the preceding year an excessively hot summer in *August (n-1)* and *September (n-1)* in unfavourable. Mountain Pine also prefers a mild late season in *November (n-l)* exactly as in the Alps (Rolland, 1993). A thermal stress and a cold autumn would probably reduce the formation of metabolitic reserves and consequently affect growth of the following year.

Minimum density is less influenced by the temperature. Cold temperatures during *October (n-1)* and *November (n-l)* may reduce the formation of reserves, leading to denser earlywood formation (Figure 5b).

On the contrary, **maximum density** is strongly affected by the mean temperature (Figure 5c). This result shows that sensitivity to temperature is primarily due to latewood formation. Most of the results are similar to those obtained with the ring width values. In particular, the latewood is denser if *August (n)* and *September (n)* are excessively hot. This is because excessive temperatures at the end of the growth period induce smaller cell formation. High temperatures in February (n) are also linked with denser latewood.

3.8. *Influence of minimum and maximum temperature*

Both these variables give similar results to those obtained with the mean temperature, but specific phenomena also appear (Figures 6 and 7) The positive influence of high temperatures in *April(n)* and *May (n)* on large ring formation is significant only for the maximum temperature but not for the minimum ones. Consequently growth is initiated when the maximum temperature exceeds a threshold level in spring. Similarly, the part played by the high temperatures in *August (n)* and *September (n)* also appears to be due to the maximum temperature. This means that the growth period is extended only if this maximum temperature remains above a threshold value

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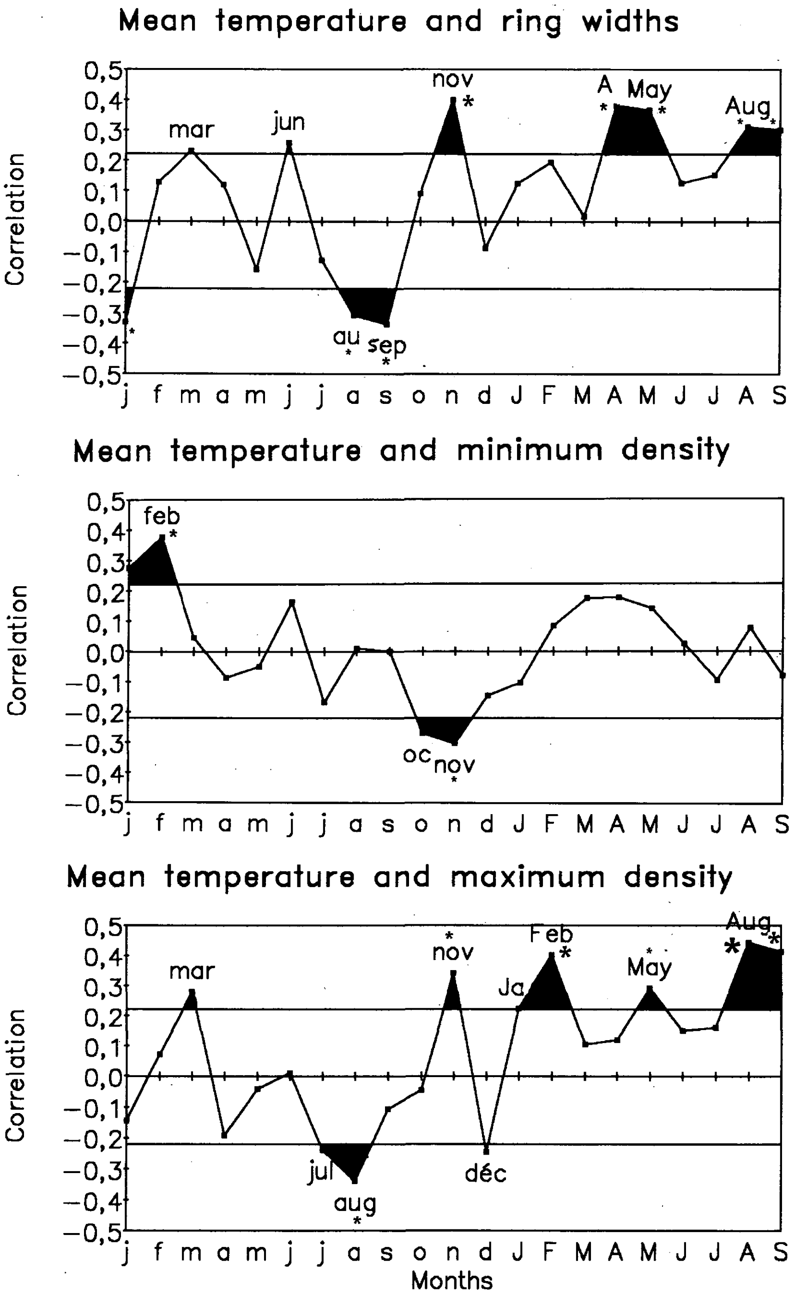

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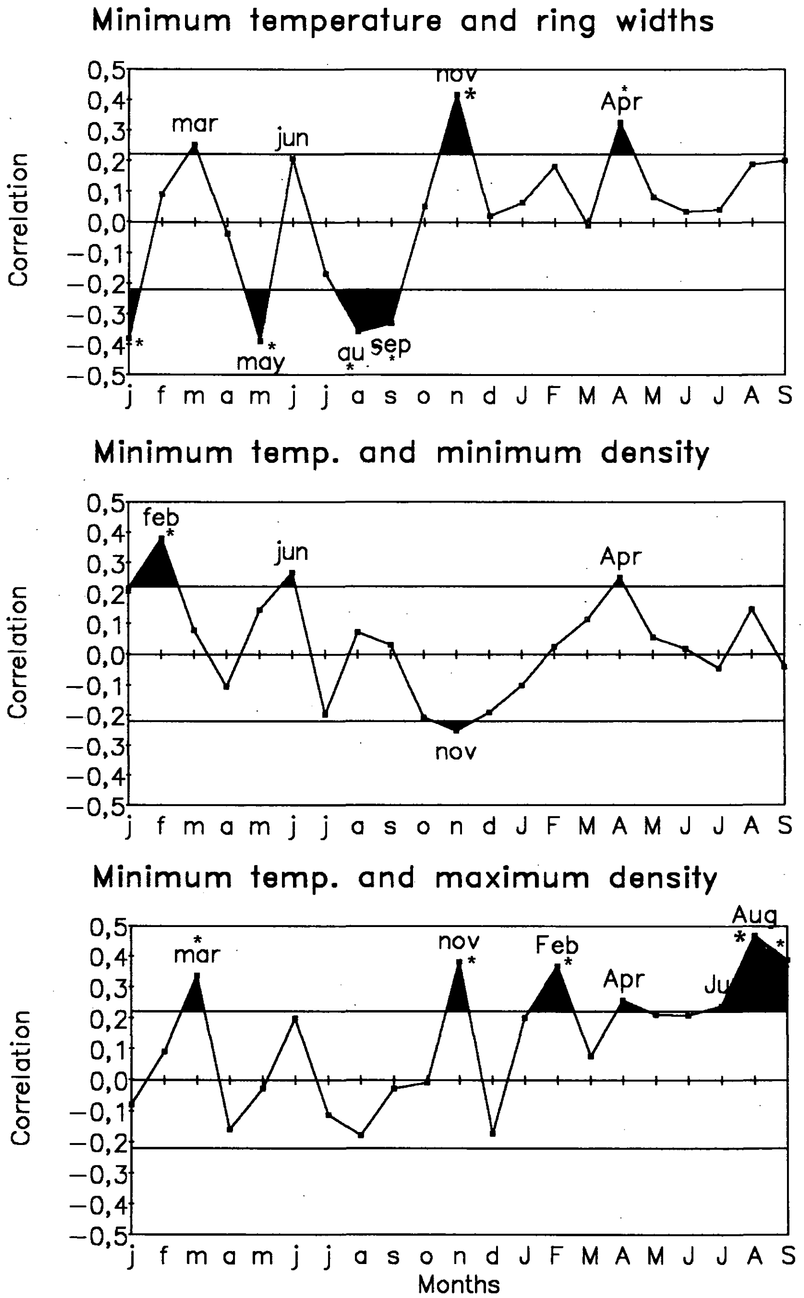

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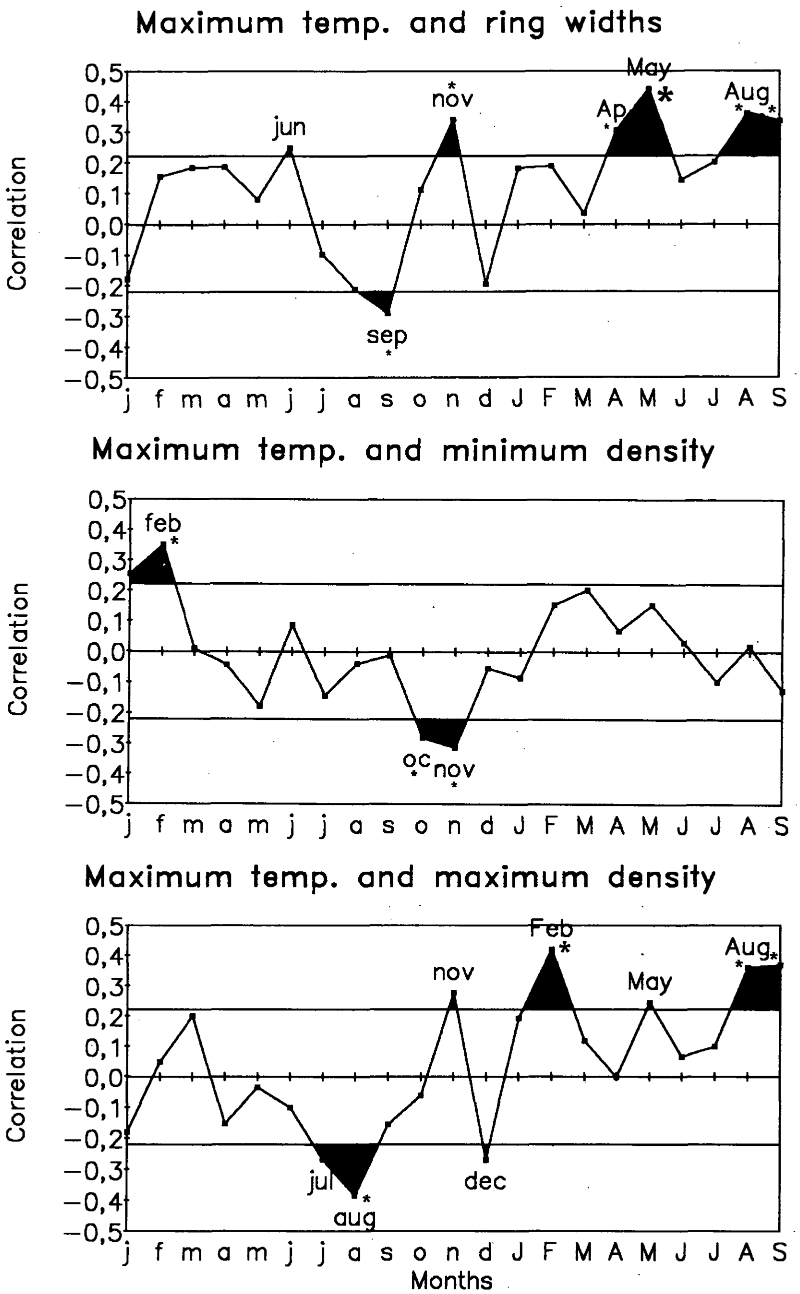

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($T_{max} > T_c$) On the contrary, the minimum temperature has less significance during this stage, since the temperature during the night is of less importance than that during the day when photosynthesis occurs.

However, the growth reduction resulting from excessive temperatures during the preceding year in *August (n-1)* and *September (n-l)* is primarily due to the minimum temperatures. Cold nights during the preceding late season seems to affect the cambium and bud initiation, so it reduces the growth. The limiting influences of temperature in *June (n)* and *July (n)* obtained in Larra do not appear here. This is probably since pines suffer less from drought in Font-Romeu (Creus & Puigdefábregas, 1976).

The **minimum density** increases if the night-time temperatures in *April (n)* are high. The maximum density shows response curves parallel to those of the ring widths. It clearly appears that the previous summer result in denser latewood if the maximum temperatures are too hot in *July (n-1)* and *August (n-1)*, but the minimum temperatures are not significant. Consecuently it is due to a thermal stress during the summer days. This phenomenon may reduce the reserves and affect the growth at the end of the following year. In *February (n)* warm days result in denser latewood therefore it seems that Mountain Pine prefers a cold winter.

3.9. *Influence of solar radiation*

In Font-Romeu the high level of solar radiation rarely plays a negative part on tree growth (Figure 8a), contrarily to in Briançon (Hautes-Alpes, France) (Rolland, 1993). Both these forests are in particularly sunny places and the Mountain Pines grow on a South facing slope, but in Font-Romeu there are enough summer rainfall. On the contrary, a higher radiation in spring in *January (n), April (n-1), March (n)* and *May (n)* is favourable to large ring formation. Consequently, Mountain Pine seems to appreciate high solar radiation here. This may explain why it is so affected by intraspecific competition and why it grows at high altitudes. It is not significantly affected by drought and a lack of sunshine seems to be unfavourable to its growth.

Minimum densities are not influenced by the solar radiation, conversely to **Maximum densities** (Figure 8b, 8c). If *June (n)*, *August (n)* and most importantly *September (n)* are sunny, it produces denser latewood because the summer and the autumn are dryer and warmer.

4. Conclusions

Mountain Pine in Font-Romeu is strongly resistant to dryness even in this dry climate, but its growth is strongly influenced by the temperature. This effect is especially due to latewood formation, since the earlywood density is less dependant on climate. This species requires spring in *April (n)* and *May*

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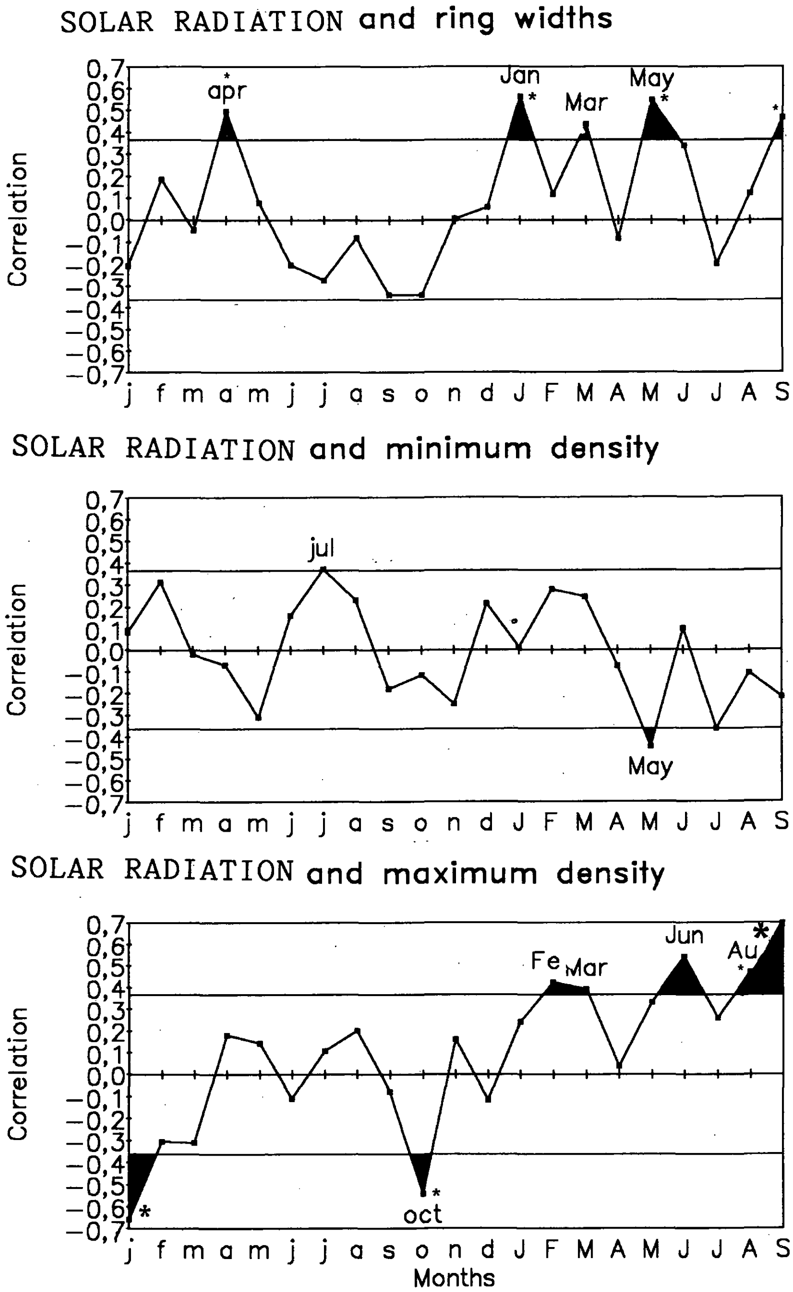

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(n) to initiate the growth of the buds and to start the cambium activity when the maximum temperatures are over a threshold value. Secondly, the growing period should be similarly extended in the autumn if the maximum in *August (n)* and in *September (n)* remain above a threshold level. Thus the maximum temperature is a limiting factor of the length of the vegetative period. Thirdly, cold nights during the preceding autumn in *September (n-1)* are unfavourable because this is when the bud and cambium initiations take place. The latewood is denser if the current autumn is excessively hot and sunny.

Acknowledgements. The authors thank J. Cooper for manuscript revision.

References

Blasing, T. J., Salomon, A. M. & Dwick, D.N. (1984): Response functions revisited. *Tree Ring Bulletin*, 44: l-15

Cantegrel, R. (1983): Le Pin à Crochets Pyrénéen: biologie, biochimie, sylviculture. *Acta Biologica Montana*, 2-3: 87-331.

Creus, J. & Puigdefábregas, J. (1976): Climatología histórica y dendrocronología de *Pinus uncinata* Ramond. *Cuadernos de Investigacion Geográfica*, 2(2),: 17-30

Fritts H.C. (1976) *Tree-ring and Climate.* Academic Press, 567 pp., London.

Génova Fernández, R. (1987): *Análisis y significado de los anillos de crecimiento de dos especies forestales: Pinus uncinata y Pinus sylvestris, en la peninsula Ibérica.* Thesis Doctoral, Departemento de Ecología, Facultad de Biológicas, Universidad de Barcelona, 355p + annexes, Barcelona.

Gutiérrez, E. (1989): Dendroclimatological study of *Pinus sylvestris* L. in Southern Catalonia (Spain). *Tree Ring Bulletin*, 49: 1-9.

Gutiérrez, E. (l991): Climatic tree growth relationships for *Pinus uncinata* Ram. in the Spanish pre-Pyrenees. *Acta Oecologica*, 12(2): 213-225.

Huber, F. (1976): Problèmes d'interdatation chez le Pin sylvestre et influence du climat sur la structure de ses accroissements annuels. *Annales des Sciences Forestieres*, 33(2): 61-36.

Keller, R. & Millier, C. (1970): Utilisation des composantes de la densité en xylochronologie. *Annales des Sciences Forestieres*, 27(2): 157-l66.

Polge, H. (1970): The use of X-ray densitometric methods in dendrochronology. *Tree Ring Bulletin*, 30:1-10.

Probst, A. & Rouane, P. (1984): Introgression entre *Pinus sylvestris* L. et *Pinus uncinata* Ramond dans la foret d'Osséja (Pyrénées-Orientales). *Documents d'Ecoloqie Pyrénéenne*, 3-4: 523-529.

Puig, J.N. (1982): *Recherches sur 1a dynamique des peuplements forestiers en milieu de montagne: contribution à l'etude de la régénération en foret d'Osséja.* Thèse 3ème Cycle, l88 pp., Toulouse.

Rolland, Ch. (1993): *Fonctionnement hydrlque et croissance stationnels comparés du Sapin (Abies alba Mill.) dans les Alpes Françaises.* Thèse Université de Grenoble, 175 pp., Grenoble.

Ruiz-Flaño, P. (1988): Dendroclimatic series of Pinus unicinata R. in the Central Pyrenees and in the Iberian System. A comparative study. *Pirineos*, 132: 49-64.

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