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. 266 – 272.

The potential of stable isotopes to record aridity conditions in a forest with low-sensitive ring widths from the eastern Pre-Pyrenees

O. Planells[1], L. Andreu[1], O. Bosch[1], E. Gutiérrez[1], M. Filot[2], M. Leuenberger[2], G. Helle[3] & G.H. Schleser[3]

[1]University of Barcelona, Department of Ecology. Diagonal 645, 08028 Barcelona, Spain
[2]University of Bern, Climate and Environmental Physics Institute. Sidlerstrasse 5, 3012 Bern, Switzerland
[3]Forschungszentrum Juelich Gmbh, Institute of Sedimentary Systems, ICG-V. 52425 Juelich, Germany
Email: octaviplanells@ub.edu

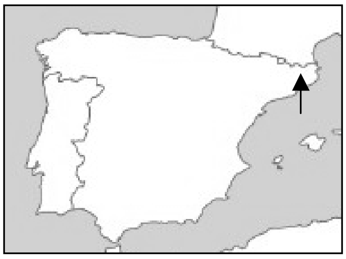
Background and objectives

The Mediterranean climate has a marked seasonality characterized by relatively cold winters, humid springs and autumns, and dry summers. The low water availability due to summer drought made species to develop special mechanisms for adaptation during their process of evolution. Independently, summer droughts have an unfavourable effect on tree growth. However, owing to topography, droughts are less frequent in some mountainous Mediterranean areas, and consequently plant growth is not that much limited in these areas by the lack of water. Tree rings of old trees are excellent climatic archives since they are sensitive to numerous environmental variables. The oldest trees around the Mediterranean basin are located close to the altitudinal tree line, far away from direct human activities.

In the present work, three different tree-ring chronologies covering 400 years were investigated with regard to ring widths (RW), $\delta^{13}C$ and $\delta^{18}O$. The corresponding trees originate from of an old sub-alpine forest that is not limited by summer droughts (Vigo et al., 2003). More specifically, the aim of this investigation was to (1) study whether stable isotopes of that region record climate variations, (2) explore whether a particular meteorological quantity is specifically recorded, and (3) estimate the climatic content of ring widths (RW) in relation to stable isotopes.

Study site

The study site is an east-facing sub-alpine forest of *Pinus uncinata* located in the Massís del Pedraforca, eastern Pre-Pyrenees (Fig. 1). *P. uncinata* forms the sub-alpine forests in the Spanish Pyrenees ranging from 1600 to 2500 m a.s.l. Previous studies performed at lower altitudes in the same mountain area (1680 m a.s.l.) showed a negative response of tree growth to July temperature, indicating a growth limitation by drought (Gutiérrez 1991). This is in contrast to the study site in this work (>2100 m a.s.l.), where rainfall is higher due to the advection of humid air masses coming from the Mediterranean Sea (annual precipitation higher than 1000 mm, June-September higher than 300 mm, mean annual temperature around 7 ºC).



Latitude	42º 14' N
Longitude	1º 42' E
Altitude	2120 m a.s.l.
Aspect	90º
Slope	36º
Substratum	Limestones, marls
Soil	Entisol, 20-50 cm depth
Forest ecological type	Oromediterranean subalpine conifer forest
Vegetation	*Juniperus communis, Pulsatilla alpina, Euphorbia* sp.

Figure 1: Map and description of the main features of the studied P. uncinata stand in Massís del Pedraforca mountain.

Methods

The individual power-transformed RW measurements were detrended by negative modified exponential or linear fitting in order to remove non-climatic trends related to tree age. Autocorrelation was also removed to get independent values and to enhance the climatic signal. The master chronology was computed with a biweight robust mean (Cook and Kairiukstis 1990).

For isotopic analyses, the whole annual rings from 4 trees (2 cores each were taken, resulting in 2 samples per year and per tree) were pooled, homogenized, and α-cellulose was extracted. δ^{13}C measurements were performed in 2 different laboratories following two different methods (combustion and pyrolysis). Although both types of measurements provide series with identical inter-annual patterns, i.e. equal relative variations, there is a shift in the absolute values of the series (Knöller et al., 2005). For correction, the difference between the means of both series was added to the annual measurements of one series. To remove the non-climatic δ^{13}C decrease observed in the raw data due to anthropogenic CO_2 emissions since industrialization, a correction was applied as suggested by McCarroll and Loader (2004). The corrected δ^{13}C series were averaged to reduce inhomogenities of each individual record ($r = 0.765$). Finally, autocorrelation of averaged measurements was removed similar to the method for RW (Monserud and Marshall 2001). It was not applied any correction to the δ^{18}O series, however autocorrelation was also removed before statistical analysis.

Calibration of tree-ring proxies and climate was performed by bootstrapped correlation (95% significance level) and single Pearson correlation analysis. We used homogenized mean monthly temperature and total precipitation of a 25x25 km grid of regional climatic records covering the years from 1931 to 2003 (Spanish National Meteorological Institute). The relationships between tree growth and climate were computed with variables from July of the year prior to tree growth (small letters; Figure 3) to October of current year (capitals). Aridity, which was expressed by a certain combination of temperature and precipitation, was one particular quantity to look at. Calibration was performed by using a simple aridity index expressing the monthly deficit of rainfall versus temperature:

$$A = Std[T] - Std[\log_{10}(P+1)]$$

where *T* and *P* are monthly temperature and precipitation, respectively. *P* is expressed as logarithms to get normalized values (*T* records are supposed to follow normal distributions). *Std* represents a scaling of both variables, according to,

$$Std_t = \frac{x_t - \bar{x}}{SD}$$

with x_t being the observed value, $\bar{x}$ the mean value of the climate records, including all the months, and *SD* its standard deviation.

Results and discussion

Figure 2 shows the standardized series. The RW chronology is statistically representative of the stand since the expressed population signal (EPS; Wigley et al 1984) for the period 1600-2003 is 0.88 (15 trees / 32 radii cover this whole period). The low mean sensitivity index and percent of variance explained by the first eigenvector (0.175 and 36%, respectively) point to a low sensitivity of RW to climate. In accordance with this result, bootstrapped correlation analysis (Fig. 3) shows only few significant relationships with temperature of the previous year (jul = 0.232; oct = 0.281; nov = 0.305), suggesting an important role of food storage on tree growth of following years. In addition, RW show some significant response to aridity, but values are very close to the significance thresholds (nov = 0.194; JUL = -0.228).

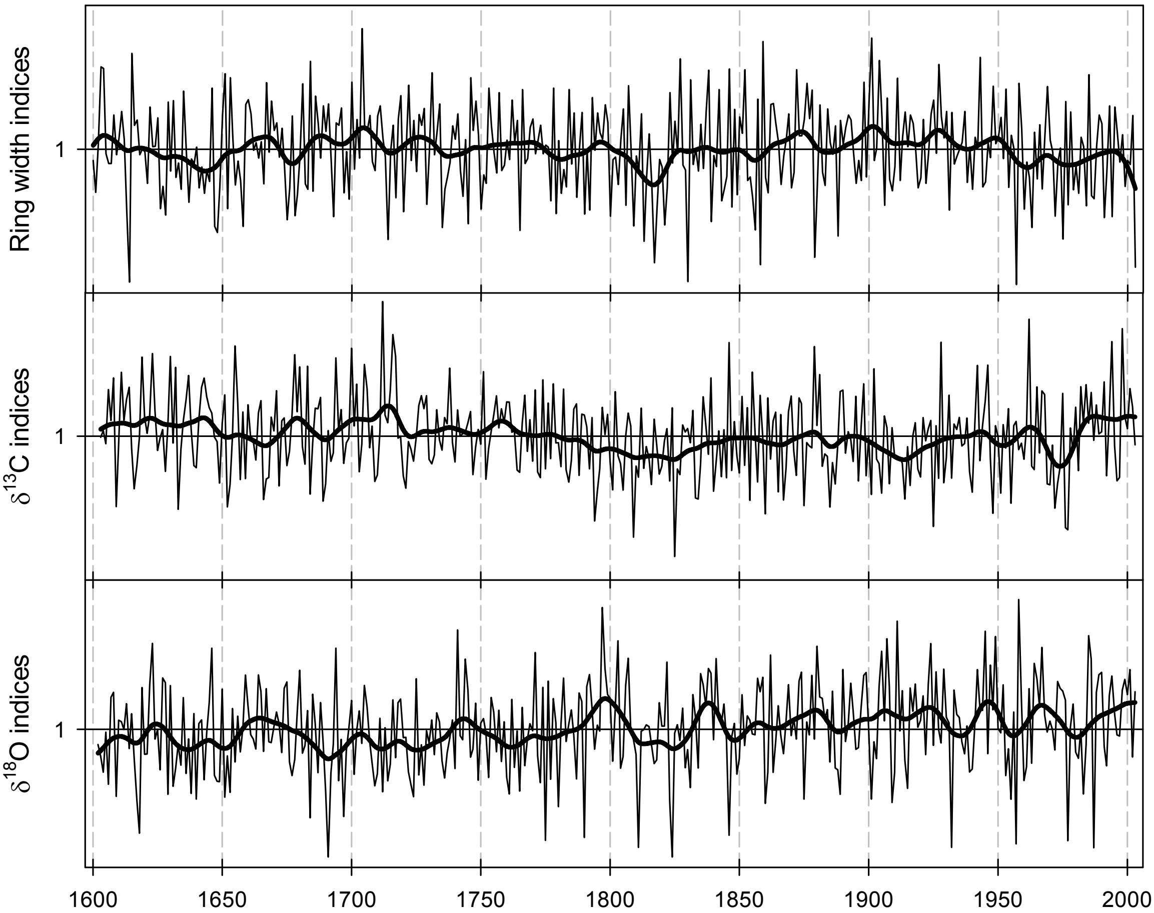


Figure 2: Ring width (top), δ^{13}C (middle) and δ^{18}O (bottom) chronologies of P. uncinata in Pedraforca. These are indexed series resulting from the different standardization procedures described in the text. The smoothed curves correspond to a 20-year spline fitting.

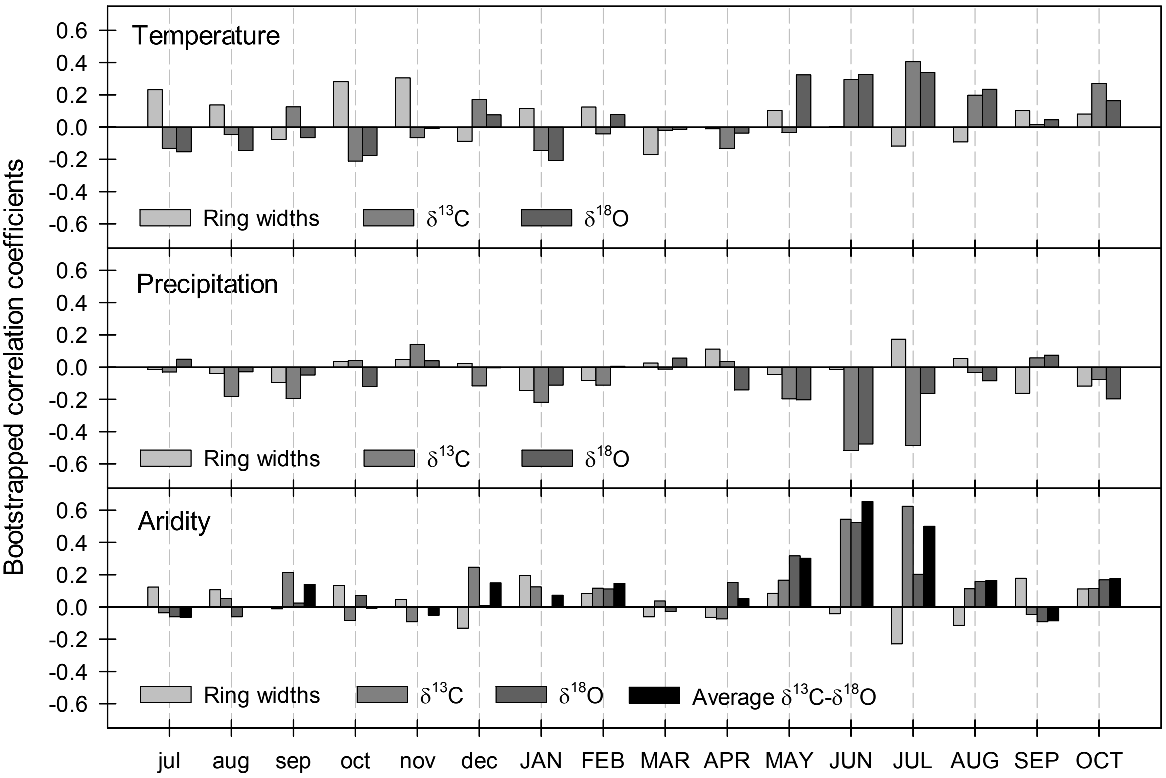
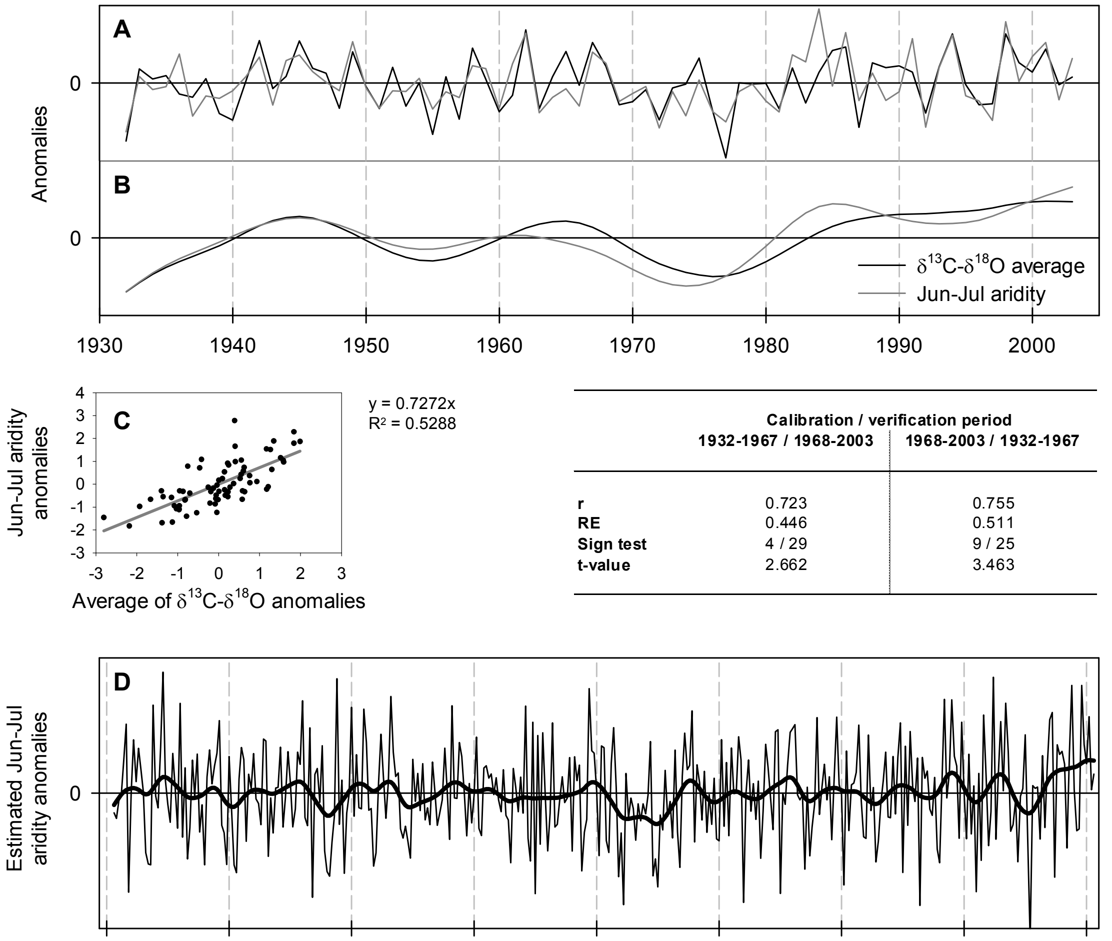


Figure 3: Bootstrapped correlation analysis performed with the different tree-ring proxies and mean temperature (top), total precipitation (middle), and aridity index (bottom) from July of the year prior to tree growth (small letters) to current year October (capitals). See text for explanation of calculations.

It is noteworthy to mention a slight negative response to current July aridity, which suggests a certain tree growth limitation due to summer water deficit. In contrast to RW, $\delta^{13}C$ data show a major response to summer climate. There is an important and significant positive relationship with temperature (JUN = 0.294; JUL = 0.405), and a negative response to precipitation (JUN = -0.516; JUL = -0.487). Correlations with summer aridity are even higher (JUN = 0.544; JUL = 0.624) and positive. These results are well in line with the Francey and Farquhar model of carbon isotope discrimination in plants (1982). This model is related to drought severity since it takes into account the stomatal aperture and the intercellular availability of CO_2 for the enzyme rubisco. According to the model, higher water stress (lower precipitation/higher temperature) results in stomatal closure and more positive $\delta^{13}C$, thus consistent with a positive sign of the regression equation for temperature and a negative sign for precipitation. There are some other relationships between $\delta^{13}C$ and monthly variables prior to the growing period, but their significance is very low. The role of reserves accumulated during the dormancy period could be an explanation of these relationships. However, most of them could be reached just by chance since their coefficients oscillate close around the significance thresholds.

Similar results as for $\delta^{13}C$ were obtained for $\delta^{18}O$. Temperature has a broader influence in terms of number of months exceeding the significance level (MAY = 0.344; JUN = 0.352; JUL = 0.340; AUG = 0.256). On the other hand, on a monthly basis, there is only one significant relationship with precipitation (JUN = -0.487). Response to aridity is also positive and significant for early summer (MAY = 0.318; JUN = 0.524), indicating a response comparable to that of $\delta^{13}C$. However, there are some dissimilarities probably caused by the different fractionation processes driving the isotope ratios in tree rings. In contrast to the causes for $\delta^{13}C$ discrimination, $\delta^{18}O$ largely depends on the isotope ratio of soil water (which is related to $\delta^{18}O$ of rain water, residence time in the soil, evaporation rates, etc.) and the enrichment of leaf water due to evapotranspiration (Yakir and Sternberg 2000). In a further step, we looked for an optimisation procedure to extract the climatic signal contained in the isotope proxies. The similar results obtained with $\delta^{13}C$ and $\delta^{18}O$, in terms of response to summer conditions and the significance of this response, indicate that a common climatic signal could be recorded in both (r = 0.200). The averaging of $\delta^{13}C$ and $\delta^{18}O$ series could reduce the non-climatic noise contained in these records, possibly favouring the common climatic variability.



	Calibration / verification period	
	1932-1967 / 1968-2003	1968-2003 / 1932-1967
r	0.723	0.755
RE	0.446	0.511
Sign test	4 / 29	9 / 25
t-value	2.662	3.463

Figure 4: (A) Anomalies of June-July aridity and the averaged δ13C and δ18O series from 1932 to 2003. (B) 20-year smoothing spline of both. (C) Scatter plot and linear regression of the variables plotted in A. (D) Reconstruction of June-July aridity covering the last four centuries after the verification of the relationship described in C. All the verification statistics (see the table) are significant at 95% probability level. (Table) r, Pearson correlation coefficient; RE, reduction of error; sign test, disagreements / agreements; t-value of the product means test.

The bootstrapped correlation coefficients obtained for the averaged series and the aridity index, are also high (MAY = 0.302; JUN = 0.654; JUL = O.501), but not notably higher than those obtained for $\delta^{13}C$ and $\delta^{18}O$ separately. However, after combining the climatic variables in clusters of months, the strongest relationship was found for the averaged $\delta^{13}C$ and $\delta^{18}O$ data. Combining June and July, computed as a mean of both months resulted in a very high correlation for the aridity index (JUN-JUL = 0.727; Fig. 4).

The high agreement shown in Figure 4 leaves the average of $\delta^{13}C$ and $\delta^{18}O$ as the best proxy record to reconstruct the summer climate of the sampled area. Strictly speaking is it, the trade-off between precipitation and temperature of June and July. The verification of these relationships for the sub periods 1932-1967 and 1968-2003 was successful in all the statistic tests. According to the relationship established with the instrumental records, the reconstructed June-July aridity anomalies show some long-term arid and humid periods. The most conspicuous anomaly is the rise of aridity that starts around 1940 and increasingly oscillates until the end of the 20th century. Noticeable is also a cool or humid period in the first half of the 19th century, and a long interval of climatic stability covering the time period from 1740 to 1800. The averaging of $\delta^{13}C$ and $\delta^{18}O$ does enhance climatic reconstructions in this region, but this method may not hold as a general rule, because in other site conditions often the two isotopes may not be influenced by the same factors.

The use of an aridity index, which integrates temperature and precipitation, makes it sometimes difficult to discern the causes of these anomalous climatic periods. In the present case, the information provided by the individual proxies is rather useful. For example, the increase of the late 20th century aridity index is also observed in the individual $\delta^{13}C$ and $\delta^{18}O$ series, being the amplitude of the oscillations slightly smaller in both records (Fig. 2). In contrast, the RW series show a slight decrease but with an abrupt decrease at the last decade, coinciding with the rise of aridity. RW showed a slight limitation by summer drought (Fig. 3).

Despite the fact that RW of the studied forest are not very sensitive to climate, the decrease in mean widths since 1930 to now coinciding with the increase of aridity could be understood as an increase in sensitivity to the changing climatic conditions.

Considering that stable isotopes respond positively to aridity, and RW negatively, coinciding trends can provide complementary information. This is e.g. the case of the negative aridity anomalies of the mid half of the 19th century. It coincides with notable tree growth suppression visible in the RW chronology. This suggests that the limitation of tree growth is not due to drought but due to the shortness of cold and wet growing seasons. This approach of combined analysis of RW and isotopes for understanding climatic changes would be worthwhile to study in more detail in a future study.

In conclusion, the results shown demonstrate that the information provided by different tree-ring proxies is complementary and sometimes can be combined to get better and more reliable climatic reconstructions. The interpretation of long-term trends and pointer years of reconstructions made with single proxies or a set of proxies, can occasionally be improved by defining indirect climate quantities such as the used aridity index being a combination of two meteorological variables.

Acknowledgements

The authors are grateful to Carlos Almarza, Javier Martín Vide and Mariano Barriendos for their help in providing meteorological resources. We also thank Henry Grissino-Mayer for supplying useful references. This research was funded by the EU project ISONET '400 years of Annual Reconstructions of European Climate Variability using a High Resolution Isotopic Network' (EVK2-2001-237).

References

Cook, E.R., Kairiukstis, L.A. (1990): *Methods of Dendrochronology*. Kluwer, Dordrecht.

Francey, R.J., Farquhar, G.D. (1982): An explanation of ^{13}C / ^{12}C variations in tree rings. *Nature 297*: 28-31.

Gutiérrez, E. (1991): Climate tree-growth relationships for *Pinus uncinata* Ram. in the Spanish pre-Pyrenees. *Acta Oecologica 12(2)*: 213-225.

Knöller, K., Böttger, T., Weise, S.M., Gehre, M. (2005): Carbon isotope analyses of cellulose using two different on-line techniques (elemental analysis and high-temperature pyrolysis) – a comparison. *Rapid Communications in Mass Spectrometry 19*: 343-348.

McCarroll, D., Loader, N.J. (2004): Stable isotopes in tree rings. *Quaternary Science Reviews 23*: 771-801.

Monserud, R.A., Marshall, J.D. (2001): Time-series analysis of $\delta^{13}C$ from tree rings. I. Time trends and autocorrelation. *Tree Physiology 21*: 1087-1102.

Vigo, J., Soriano, I., Carreras, J., Aymerich, P., Carrillo, E., Font, X., Masalles, R.M., Ninot, J.M. (2003) *Flora del Parc Natural del Cadí-Moixeró i de les serres veïnes (Prepirineus orientals ibèrics)*. Monografies del Museu de Ciències Naturals 1, Institut de Cultura, Ajuntament de Barcelona, Barcelona, 407 pp.

Wigley, T.M.L., Briffa, K. R., Jones, P.D. (1984): On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Climate and Applied Meteorology 23*: 201-213.

Yakir, D., Sternberg, L.S.L. (2000): The use of stable isotopes to study ecosystem gas exchange. *Oecologia 123*: 297-311.