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INFLUENCE OF CLIMATE ON RADIAL GROWTH OF HOLM OAKS (QUERCUS ILEX SUBSP. BALLOTA DESF) FROM SW SPAIN

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Abstract: A total of 47 trunk sections from Holm Oak (Quercus ilex subsp. ballota Desf) trees growing at two different sites at the Extremadura region (SW Spain) were considered in the computation of a regional tree-ring chronology useful to interpret the tree-ring/Mediterranean climate relationships. This is the first dendroclimatological research of Holm Oaks conducted to reveal its potential use as a climatic proxy. The obtained tree-ring chronologies were compared with climatic parameters based on monthly, seasonal and annual rainfall, and monthly maximum, minimum and average temperature. The best correlations were obtained with maximum temperatures during the period between previous winter and early spring. Influence of rainfall was less relevant. Growth of this species indicates a typical bimodal (spring and autumn) strategy that avoids low winter temperatures and summer drought. Despite some technical difficulties recognizing tree rings in Holm Oaks, its good sensitivity to climate variability and its wide distribution and longevity (~800 years), allow us to consider this species as a good candidate for temperature reconstructions in the Mediterranean Basin.

Keywords: *Quercus ilex*, dendrochronology, dendroclimatology, tree rings, maximum temperature, climatic change, Extremadura, Spain.

1. INTRODUCTION

Tree rings have been used extensively in temperate regions to reconstruct forest responses to past environmental changes. In the western area of the Mediterranean Basin, dendrochronological studies are scarce when compared with other areas of Europe (Patón *et al.*, 1993; 1998; 2006a; 2006b; 2006c; Caritat *et al.*, 1996; 2000; Nabais *et al.*, 1998-1999; Costa *et al.*, 2001). However, the analysis of tree rings is important to understand and predict the effects of climate change and desertification consequences (Meko *et al.*, 1995; Le Houérou, 1996; Puigdefábregas and Mendizábal, 1998; Touchan and Hughes, 1999). Therefore, it is urgent to find climate proxies widely distributed along the Mediterranean Europe that allow us to extend the knowledge of the past climate (Serre-Bachet *et al.*, 1992; Glueck and Stockton, 2001; García-Herrera *et al.*, 2007). Different tree species from Mediterranean Europe have been used in dendroclimatic studies but, at present, scarce information from Holm Oak (*Quercus ilex* subsp. *ballota* Desf) exists. Holm Oak is a drought-tolerant species (Martínez-Vilalta *et al.,* 2002) widely distributed in the Mediterranean Basin where approximately 60% of this kind of forest (commonly named "dehesa") is located in Spain. From a total coverage of 2,889,341 ha in the Mediterranean basin, 831,000 ha are present in the Extremadura region (Corcuera *et al.*, 2004). In this area, the Holm Oak forests represent 74.82% of the total forest surface, where the rest is vegetated by other Mediterranean *Quercus* species such as Cork Oak (*Quercus suber* L.), Pyrenean Oak (*Quercus pyrenaica* Willd.), Portuguese Oak (*Quercus faginea* Lam.), Kermes Oak (*Quercus coccifera* L.), and other tree species such as Sweet Chesnut (*Castanea sativa* L.), Maritime Pine (Pinus pinaster Ait), Stone Pine (*Pinus pinea* L.) or river forests with Willow (*Salix spp.*), Black Alder (*Alnus glutinosa* L.) and Narrow-leafed Ash

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(*Fraxinus angustifolia* Vahl.). Holm Oak can be found along a wide altitudinal range (0-2,000 m a.s.l.), although the majority of the forest stands appear between 400-1,200 m a.s.l, both on siliceous and calcareous soils. Holm Oaks need a minimum rainfall of 100 mm, with an optimum of 600 mm but can also be located in areas with 800 mm of rainfall given mixed forests on sunny slopes. Different botanical and phytogeographical studies indicate that Holm Oak includes two subspecies different in morphology and distribution. They are *Q. ilex* L. subsp. *ilex,* restricted to mild, coastal areas from Greece to France, and *Q. ilex* L. subsp. *ballota* (Desf.) Samp., dominant in continental sites in Spain and N. Africa (Saenz, 1967; Tutin *et al.,* 1993; Blanco *et al.*, 1997). Lumaret *et al.* (2002) indicates that the early genetic differentiation between both subspecies was caused by the contrasting climatic conditions of their distinct geographical areas. Average temperature requirements of Holm Oak vary between 10°C in winter and 25°C in summer.

Certain studies indicate that *Quercus ilex* and *Quercus suber* forests are decreasing in surface and viability during recent decades due to insect damage, fungal diseases, overgrazing, overbrowsing and inadequate forest management practices (Patón *et al.*, 1999; Pulido *et al.*, 2001; Rodríguez *et al.*, 2003; 2005; Plieninger *et al.*, 2004; Martín *et al.*, 2005). Also, there is evidence of spring rainfall reduction and increase in winter temperatures in Western Iberia in the last forty years (Del Rio *et al.*, 2004; Paredes *et al.*, 2006; Serrano *et al.*, 1998). These effects increase the water stress on Mediterranean forests during spring and thus their vulnerability to different fungal and insect diseases in winter (Hódar *et al.*, 2003; Puerto and Rico 1989). Therefore it is very important to define the degree of influence of rainfall and temperature on Holm Oak tree rings, not only for ecological purposes but also to interpret the past climate variability from their tree rings. Despite the importance of Holm Oak in the economy and environment of SW Spain, no dendroclimatological studies have been carried out with old trees of this species. Only certain studies demonstrate the incidence of water deficit in radial growth of stems, root sprouts, branches or in young trees (Corcuera *et al.*, 2004; Cherubini *et al.*, 2003). Our study is the first one searching the relations between climate and radial growth by dendroclimatic techniques in adult Holm Oak trees. In the present paper, we assess a methodology for the recognition of tree rings in this species and the response of Holm Oak tree rings to climate. We use non-parametric correlation analysis to detect the influence of 68 climatic parameters on radial growth. We suspect that the decrease of spring rainfall and increase in temperatures detected

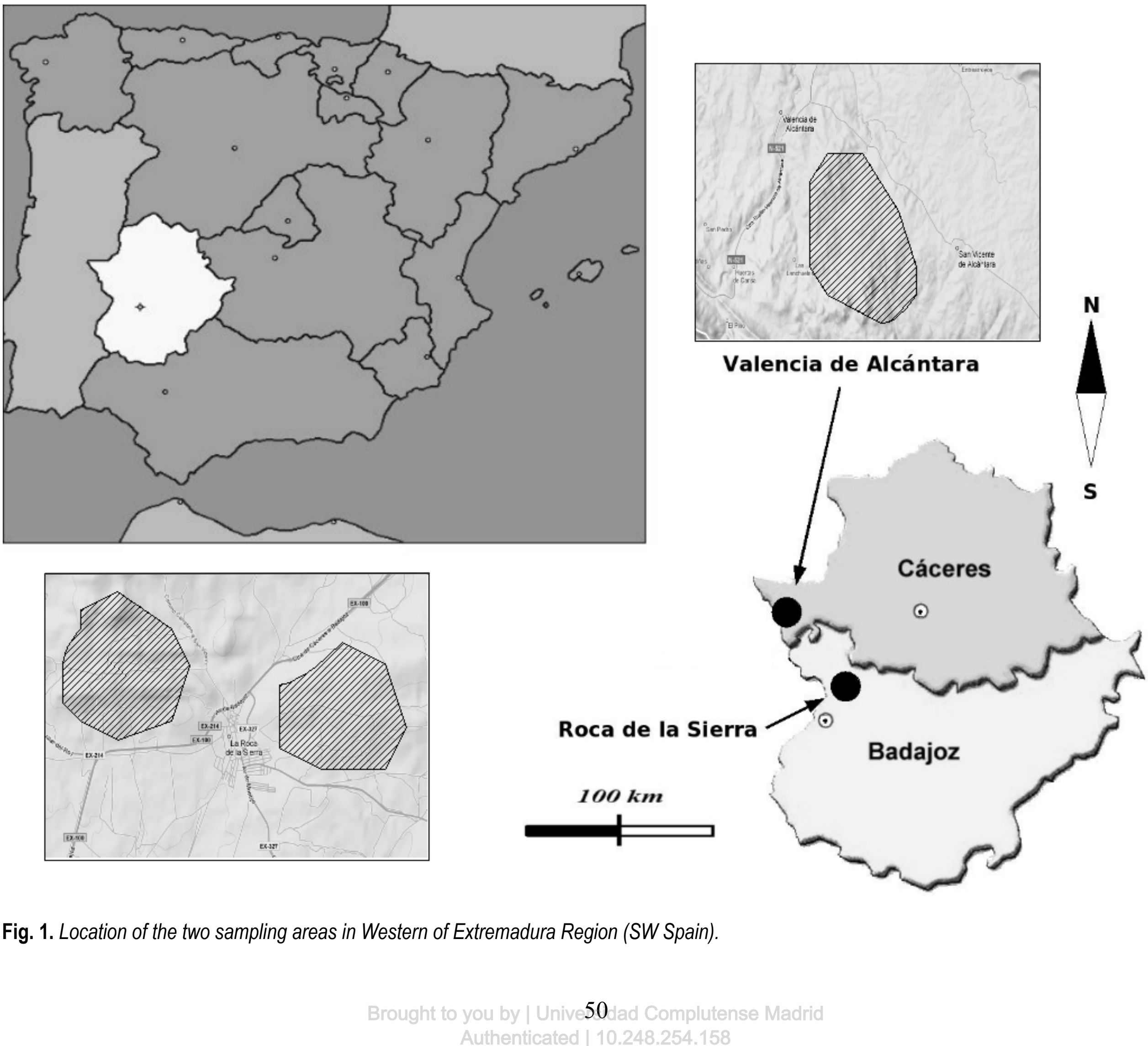

Fig. 1. *Location of the two sampling areas in Western of Extremadura Region (SW Spain).*

from instrumental records and from our tree-ring analysis, might seriously compromise the survival of the main Mediterranean forest in SW Spain.

2. MATERIAL AND METHODS

Study area

The study area is located in the southwestern Iberian Peninsula. Two Holm Oak stands separated from each other by 50 km were selected for the dendrochronological sampling: "Roca de la Sierra" (BA, Spain – 39º06'N, 6º41'W, 248 m a.s.l.) and "Valencia de Alcántara" (CC, Spain – 39º24'N, 7º14'W, 461 m a.s.l.) (**Fig. 1**). The annual rainfall for the area is 623.9 mm and the mean annual temperature is 16.4°C with daily records ranging in the instrumental period between a daily maximum of 44°C in July and a daily minimum of -3°C in January. The dry season usually occurs from May to September and precipitation is concentrated from October to April. This climatic information corresponds to the average of the two weather stations, "Roca de la Sierra" and "Valencia de Alcántara", during the period between 1950 and 2007 (**Fig. 2**).

The predominant soils in the area are identified as dystri-endoleptic, dystri-epileptic and dystric Cambisols. The texture is clay loam to sandy clay loam with clay content higher than 8%. The organic matter content oscillates between 1-2% and the CIC is between 16-25 $cmol_{(+)}kg^{-1}$. The base saturation is close to 63% and the pH oscillates between 5.5-6.0, although the acidity decreases with depth. Soil moisture shows great fluctuations during the year in agreement with meteorological data.

The potential vegetation corresponds to a mixed Mediterranean sclerophyllous forest dominated by Holm Oak (*Quercus ilex* subsp. *ballota* Desf) and Cork Oak (*Quercus suber* L.) trees with shrublands composed by *Cistus salvifolius* L., *Cistus ladanifer* L., *Genista hirsuta* Vahl, *Lavandula stoechas* L. and *Phillyrea angustifolia* L. The sampling area is exploited under the traditional "dehesa" management, usually based on an agro-silvopastoral system where Holm Oaks are used for acorn production and Cork Oaks for cork extraction (Olea and San Miguel, 2006). The herbaceous layer is used for grazing and certain pasture improvement based on tillage and phosphoric fertilization is only applied in the population of "Roca de la Sierra" (Badajoz province). The "Valencia de Alcántara" population presents a light forest management based in occasional and moderate pruning.

Sampling procedure

In the present study we worked with 47 trunk sections obtained at DBH (Diameter at Breadth Height) from two populations: Roca de la Sierra (n=31) and Valencia de Alcántara (n=16) (**Fig. 1**). These samples were obtained from Holm Oaks cleared by road constructions or trees killed by the forest fires that destroyed 25,836 ha from Spain and Portugal during the very hot summer of 2003 (González *et al.,* 2007). The trees were selected inside the sampling areas by its larger trunk size and right growth habits (**Fig. 1**). Both sampling areas are close to climatic stations and showed similar ombroclimatic diagrams (**Fig. 2**). Climatic information was obtained from the Spanish National Institute of Climatology in Badajoz (Spain) covering 48 and 62 years for "Valencia de Alcántara" and "Roca de la Sierra" stations respectively. In the laboratory the samples were polished firstly with a Virutex LB31E belt sander using sandpaper of grain size of 60, 80, 120 and 250 and finishing with orbital sander Black&Decker KA190E using sandpaper up to grain size 400, 800 and 1200. The different sections were scanned to very high resolutions (9600 dpi) and ring widths were measured with CAD Software (Q-CAD) using a Debian GNU Linux operating system. Due to the sinusoidal form of the tree ring boundaries (**Fig. 3**) and the possible influence of this factor on measuring and cross-dating steps, we performed four radial measurements for each trunk section that were averaged for each one of the 47 trees and finally only a single series by tree was used in inter-tree comparisons and average (Patón *et al.*, 2006b).

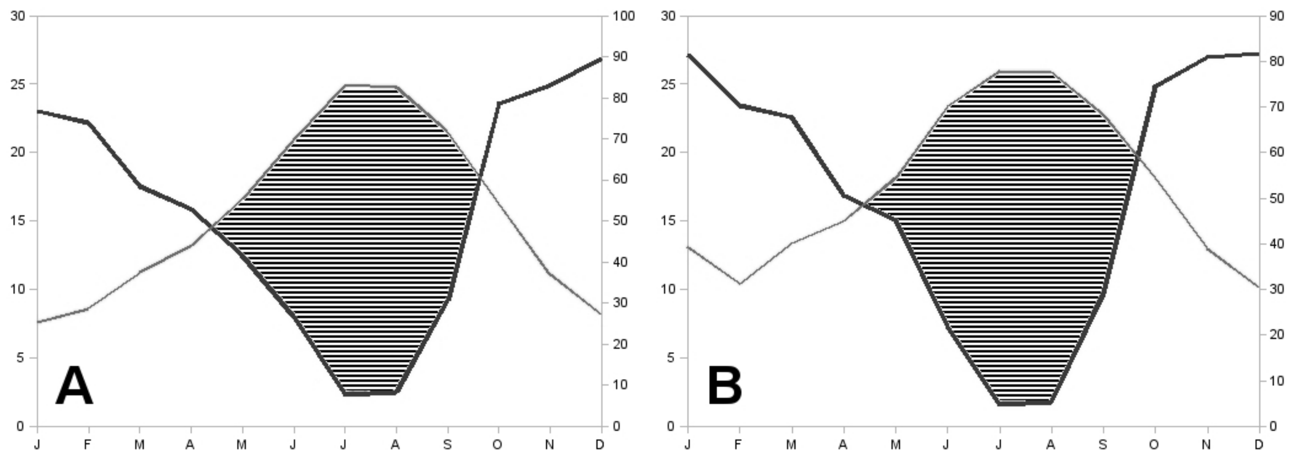

Fig. 2. *Ombroclimatic diagrams for Valencia de Alcántara (A) and Roca de la Sierra (B) in Extremadura region (SW Spain).*

Statistical analysis

Data quality was validated using the computer program COFECHA (Holmes, 1983). To compute the ring width index chronology, the computer program ARSTAN was used (Cook, 1985). The common signal strength in the series was determined by RBAR (Wigley *et al.*, 1984). RBAR is defined as the average correlation between all the series, which is an expression of the percentage variance in common. We estimated another statistics, the expressed population signal (EPS), that express the relationships between a finite sample chronology and the theoretical population chronology (Wigley *et al*, 1984). EPS is very dependent on the number of trees used in the chronology and according to Wigley et al (1984) its value must be above 0.85. The raw ring-width data was standardized to remove growth rate due to age-related trends and particular differences among trees. According to this principle, a cubic smoothing 32-year spline with a 50% frequency response is fitted to the measured ring-width time series. The use of this spline stiffness flexibility minimizes the non-climatic variances attributed to increasing age, tree size, grazing, pruning intensity, density and changes in the supply of soil nutrients (Fritts, 1976; Cook and Kairiukstis, 1990). Both final standard and residual chronologies were tested against the 68 climatic parameters using a Spearman rank correlation index. The climatic parameters were monthly, seasonal and annual rainfall, maximum, average and minimum temperatures. The fitting of the tree-ring series against climate was performed by an Artificial Neural Network (ANN). Helama *et al.*, 2009 find similar behaviour of ANN to Multiple Linear Regression for Lapland trees. However, Carrer and Urbinati (2001) obtain better results in the description of the modal relationships between temperature and radial growth of different tree species in the Alps. In our opinion, ANN is a very good procedure that permits analyzing the optimum of climate-growth relationships. All the statistical analysis was made with the STATS and NNET programs under R environment in a Debian GNU Linux workstation (R Development Core Team, 2003).

3. RESULTS

Distinction of Tree Rings

Holm Oak is a ring to semi-diffuse-porous wood with multiseriate rays that can disturb the fine distinction of the tree ring boundaries (**Fig. 3**). These rings can be accurately recognized only after a very careful polishing with the finest sandpapers. An additional problem with this species is the sinusoidal tangential form of the tree ring boundary that produces a variable distance between rays (**Fig. 3**). In order to solve these problems we measured four rays per tree. The studies of Corcuera *et al.* (2004), using branches and root sprouts, demonstrate that this species forms false rings as a consequence of the typical variability of Mediterranean climate, associated to precipitation variability during late summer or early autumn. False rings are produced when July-August rainfall is low and September-October is higher. These conditions have been more frequently produced during the last decades and only affect certain trees. In consequence, false rings were easily detected by crossdating. Another problem was the extremely narrow rings of the external area of the oldest trees. To solve this problem, we increased the sample size with young trees which present wider rings that were easier to measure.

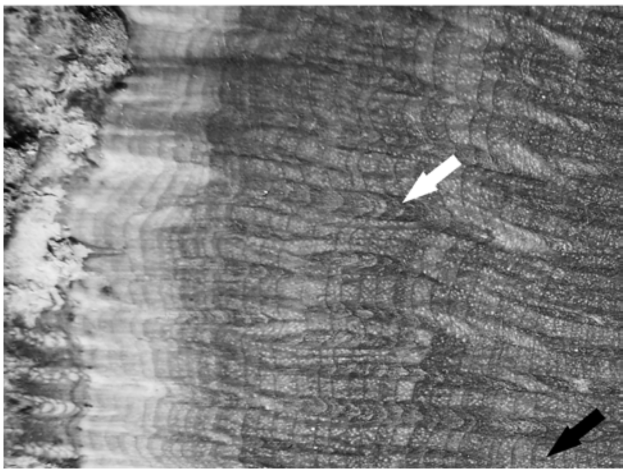

Fig. 3. *Visualization of tree rings in Holm Oak (Quercus ilex subsp. ballota Desf). Medullar radius (white arrow) and false rings (black arrow) can be observed.*

Cross-dating

Initial trials with this species gave poor cross-dating results using graphical and statistical techniques. Only after four radii per section were used, false rings and other dating mistakes were easily detected (**Fig. 3**). Also, cross-dating comparison between the different site populations were determinant in the dating quality control due to the marked microclimate differences between these sites. In particular, the population of "Roca de La Sierra" (Badajoz) showed more intense short-time perturbations by livestock and pruning, a factor that undoubtedly may affect cross-dating. In contrast, the population of "Valencia de Alcántara" (Cáceres) experienced a very low level of pruning. This population shows a higher frequency of late summer storms that has been related to a higher incidence of false rings (Corcuera *et al.,* 2004). In contrast, the population of Badajoz Province shows a lower incidence of the late summer storms, and probably a lower incidence of false rings. Missing rings were 0.38% and 0.07% respectively for both populations. The correlation matrix computed using all the trees of both populations,

Table 1. *Results of COFECHA program for populations of "Valencia de Alcantara" (VA), "Roca de la Sierra" (RS) and both.*

Parameter	VA	RS	Both
Number of trees (series)	16(32)	31(72)	47(104)
Number of years of master series	78	247	248
Total rings in all series	1047	2526	4599
Total dated rings checked	1045	2522	4597
Series intercorrelation	0.57	0.52	0.54
Average mean sensitivity	0.20	0.37	0.32

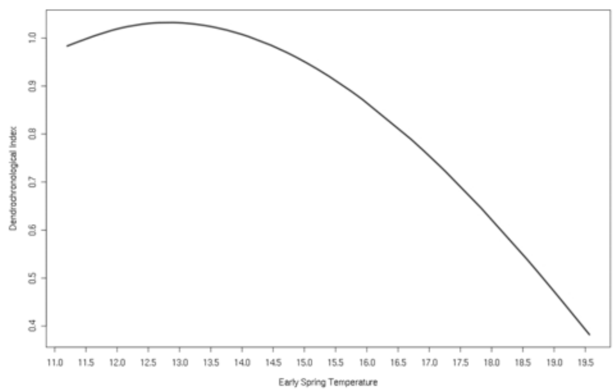

Fig. 4. *Artificial Neural Network Response function of dendrochronological index in regard to average maximum temperature in the period between late winter and early spring.*

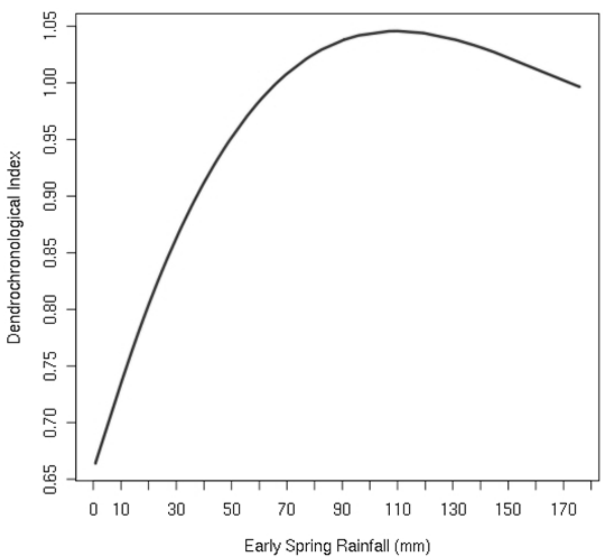

Fig. 5. *Artificial Neural Network Response function of dendrochronological index in regard to early spring rainfall in the period between late winter and early spring.*

indicates an average correlation of 0.54 (significant at $p<0.05$) between individual tree ring-width time series and a mean sensitivity of 0.32 (**Table 1**). These values are certainly higher compared with data obtained from other Mediterranean species (Cherubini *et al.*, 2003). RBAR for "Alcantara" and "Roca" populations were 0.174 and 0.119 respectively. However, the joined analysis of both populations give a value of 0.229. EPS for "Alcantara" and "Roca" populations were 0.769 and 0.745 under the critical value of 0.85 (Wigley *et al.* 1984). The analysis of joined effect of both populations show a value of 0.864 over the critical value and very similar to results obtained by Roig *et al.* (2009) with Sweet Chesnut (*Castanea sativa* Miller) in the North of Extremadura region.

Determination of Standard and Residual series

The statistics values obtained from ARSTAN indicates good performance (**Tables 2**), although worse than for other Mediterranean species such as those belonging to the genus *Pinus*, *Castanea* or *Quercus* (Tardif and Conciatori, 2006; Patón *et al.*, 2006c). The non-perturbed population of "Valencia de Alcantara", located in a mountainous area far of the optimum niche of this species, showed the higher values of the signal to noise ratio and agreement with population chronology (**Table 2**). In contrast, the "Roca de La Sierra" population presents higher values of the mean sensitivity and variance in the first eigenvector (**Table 2**). When tree-ring series from both populations are mixed (**Table 2**, the variance due to the first eigenvector increases while the values of the other parameters decrease. Consequently we use both populations for independent comparisons with climate. Despite the high inter tree variability in growth, genetics, physiology, acorn production or even acorn composition (Corcuera *et al.*, 2002; Cañellas *et al.*, 2007; Moreno and Cubera, 2008), Holm Oak is a good climate indicator.

Comparisons between tree rings and climate

Table 5 shows the results of Spearman rank correlation tests on monthly, seasonal and annual rainfall and maximum, minimum and average temperatures. Results show a slight influence of spring, winter and autumn rainfall on tree ring widths. Regarding temperatures, the best correlation was obtained by comparison of tree growth with January maximum temperature (**Table 3**). Using an Artificial Neural Network (ANN) analysis, we explored the influence of air temperatures in the seasonal growth ring formation of Holm Oak trees (**Fig. 4**). This analysis also shows that the maximum growth in this species is obtained at around 13°C of average maximum air temperature during January, February and March, and decreases markedly with temperatures over 16°C during

Table 2. *Parameters of ARSTAN program for Standard and Residual chronologies for populations of "Valencia de Alcantara" (VA), "Roca de la Sier (RS) and both.*

	Standard			Residual		
Parameter	**VA**	**RS**	**Both**	**VA**	**RS**	**Both**
Mean sensitivity	0.14	0.23	0.16	0.11	0.26	0.18
Common interval mean and standard deviation	1.00±0.17	0.97±0.18	0.96±0.17	0.99±0.11	0.98±0.17	0.97±0.16
Skewness	0.49	0.27	-0.41	-2.27	-0.07	-0.29
Kurtosis	3.50	2.58	1.73	8.45	2.69	2.74
Autocorrelation first-order	0.27	0.27	0.23	0.01	-0.08	0.01
Signal to noise ratio	10.63	4.88	3.24	11.04	5.01	3.42
Agreement with population chronology	0.91	0.83	0.76	0.92	0.83	0.77
Variance in first eigenvector	26.22%	28.61%	29.41%	26.42%	25.89%	29.66%

Table 3. *Correlations between monthly, seasonal and annual rainfall (P), average (T), maximum (TM) and minimum temperature (Tm) with Standa and Residual chronologies.*

	Standard				Residual			
	P	T	TM	Tm	P	T	TM	Tm
January	0.08 ns	-0.33 *	-0.53 ***	-0.02 ns	0.06 ns	-0.12 ns	-0.28 *	0.08 ns
February	0.31 *	-0.28 *	-0.32 *	0.15 ns	0.34 *	-0.19 ns	-0.33 *	0.29 *
March	0.34 **	-0.35 **	-0.41 **	0.13 ns	0.38 **	-0.11 ns	-0.25 ns	0.35 **
April	-0.09 ns	-0.17 ns	-0.20 ns	0.21 ns	-0.05 ns	-0.06 ns	-0.08 ns	0.19 ns
May	-0.27 *	-0.02 ns	-0.08 ns	0.22 ns	-0.30 *	0.06 ns	-0.00 ns	0.27 *
June	0.01 ns	-0.27 *	-0.34 **	0.09 ns	-0.11 ns	-0.07 ns	-0.12 ns	0.11 ns
July	-0.00 ns	-0.09 ns	-0.33 *	0.55 ***	-0.20 ns	0.06 ns	-0.11 ns	0.45 ***
August	-0.16 ns	-0.05 ns	-0.16 ns	0.22 ns	-0.23 ns	0.02 ns	-0.13 ns	0.25 ns
September	-0.10 ns	-0.10 ns	-0.18 ns	-0.01 ns	0.00 ns	-0.06 ns	-0.20 ns	0.04 ns
October	-0.06 ns	-0.29 *	-0.20 ns	-0.08 ns	-0.09 ns	-0.15 ns	-0.19 ns	0.04 ns
November	-0.28 *	-0.18 ns	-0.25 ns	-0.14 ns	-0.20 ns	-0.08 ns	-0.02 ns	-0.14 ns
December	-0.03 ns	-0.26 *	-0.16 ns	-0.16 ns	0.02 ns	-0.02 ns	0.08 ns	-0.08 ns
Spring	-0.01 ns	-0.18 ns	-0.23 ns	0.23 ns	0.11 ns	0.01 ns	-0.11 ns	0.31 *
Summer	-0,02 ns	-0.20 ns	-0.37 **	0.38 **	-0.22 ns	-0.01 ns	-0.14 ns	0.38 **
Autumn	-0.28 *	-0.29 *	-0.30 *	0.10 ns	-0.23 ns	-0.16 ns	-0.18 ns	-0.00 ns
Winter	0.11 ns	-0.38 **	-0.46 ***	-0.04 ns	0.20 ns	-0.13 ns	-0.23 ns	0.13 ns
Annual	-0.16 ns	-0.28 *	-0.44 ***	0.17 ns	-0.11 ns	-0.04 ns	-0.22 ns	0.26 ns

the same months. Considering rainfall data in the ANN analysis, we found that the maximum growth in Holm Oak trees is obtained at the level of 110 mm of rainfall fallen during February and March (**Fig. 5**).

4. DISCUSSION

Although a suite of dendrochronological studies under the Mediterranean climate indicates that several species are useful for ecological and paleoclimate research (Roig *et al.*, 2006), the present paper indicates that Holm Oak is a valuable tree species for dendrochronological research in south western Iberia, one of the critical rainfall fluctuation regions of Europe linked to the North Atlantic Oscillation variability (Trigo *et al.*, 2006). Holm Oak is a tree species with a ring-to-diffuse porous wood structure, that suggests an adaptation to drought conditions (Zhang and Romane, 1991; Terradas and Savé, 1992; Villar *et al.*, 1997; Terradas, 1999; Corcuera *et al.*, 2004). However, this structure produces difficulties in the identification of tree ring boundary. In the Extremadura region, pruning and grazing activities on Holm oaks forest are extended practices used to improve the tree productivity. This fact may introduce modifications in tree ring values by factors other than the influence of climate and consequently may lower the common growth pattern necessary for successful cross-dating and growth-climate comparisons. In order to avoid these problems, we sampled in areas with low incidence of these management practices such as the region of “Valencia de Alcántara” in Eastern Extremadura. According to the present results, the Holm Oak trees demonstrate to be a good candidate to extend the dendrochronological studies in Mediterranean areas of Spain. However, for climatic reconstruction RBAR, very dependent on sample size, is slightly low indicating the necessity of increase sampling size to more populations and trees. Holm oaks present a high longevity compared with other tree species of the genus *Quercus* and shows a wide distribution due to its high adaptability and ecological valence (Panaïtois *et al.*, 1997; Nardini *et al.*, 2000; Pañuelas *et al.*, 2000; 2001; Ogaya *et al.*, 2003). Moreover, the sensitive response of Holm Oak growth to climate variability places this tree species as a potential high-resolution climate proxy from southern Europe and northern Africa (Luterbacher *et al.*, 2006 and references therein, García-Herrera *et al.*, 2007). According to the IPCC fourth Assessment (Meehl *et al.*, 2007), the annual precipitation and number of precipitation days are decreasing in the Mediterranean Basin. At seasonal scales, the decrease should be higher (around 40 per cent) in the summer precipitation than during the winter, which could be reduced 10-15 per cent. Other studies show an increase in winter temperatures (García-Herrera *et al.*, 2007). Both changes induce a trend towards a semi-tropical climate type. *Quercus ilex* is a typical Mediterranean species adapted to intense variability in temperature and rainfall, variability that had been detected in the area for millennia (Blanco *et al.*, 1997). This physiological adaptation to a Mediterranean climate forces the Holm Oak to a bi-modal growth behaviour in response to climate. Nevertheless, autumn growth is less relevant in the total ring formation than the spring growth. If the climate in Extremadura is changing towards a semi-tropical two-season model with a decrease of spring rainfall and increase in winter temperatures, the effect over the Holm Oak growth is uncertain. The intense Mediterranean forest decrease experienced during the last decades could be linked to these climatic incidences.

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