Dendrochronological comparison of *Castanea sativa* Mill. and *Quercus pyrenaica*Willd. in southwest Spain

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Introduction

Chestnut (*Castanea sativa* Mill.) is a widely used species both for its fruit and wood harvests. The species has been introduced in Extremadura (SW Spain) in mid-mountain areas with almost 100 mm summer rainfall (Álvarez et al. 2000, Patón et al. 2006). This is the case in the "Sierra de Montánchez" (SM), an isolated mountainous area reaching 1000 m asl, where chestnut plantations have been established in the early 19th century replacing *Quercus pyrenaica* Willd. natural forests. Since then, it was common practice that both species, chestnut and oak, share certain ecological habitats (Álvarez et al. 2000), with chestnut being preferred due to its economic benefits in wood and fruit production.

SM is considered a special site with specific climate conditions allowing for forest coppice. Since the late 1960s, wood demand decreased due to the use of new materials. Accordingly, SM chestnut forest harvest terminated, and the administrative status of the forest changed towards a 'protected park'. With non-active forest management applied since then, a gradual decline of chestnut and subsequent invasion of other tree and shrub species occurred. The chestnut forests began to fragment and Pyrenean oak invaded into the habitat. This process of habitat regains and species replacement is widespread in the Mediterranean area after the termination of coppicing management (Fonti et al. 2006).

We here apply dendrochronological methods to study and compare tree ring width (TRW) variations in chestnut and oak in a shared habitat of SM over the past decades. We analyze the response of these species to different climate indexes to assess the sensitivity to changing environmental conditions in the Extremadura region, and to assess the dynamics of chestnut/oak competition.

Materialand methods

The Ecology unit of the University of Extremadura worked in different sampling campaigns in SM chestnut forest. In 2004, 6 *Castanea sativa* trees were sampled, obtaining 12 cores using increment borers. In the same way, 13 *Quercus pyrenaica* trees were drilled in 2011, obtaining 23 appropriate cores. In both sampling, the trees were selected from the bound of a chestnut coppice forest and inside including the young and old trees at 39 º 12 '58.85 "N and 6 º 08' 27.23" W, 800-825 m asl with a NW exposure. The samples were treated in the laboratory according to standard methodology (Speer 2010). A first visual crossdating was conducted using the Yamaguchi method, which consists of a classification of tree-rings according to their relative characteristics in diameter and/or special morphologies (Yamaguchi 1991) to establish an initial calendar.

The samples were then scanned at high resolution (2400 pixel ppp equal to approximately 0,011mm) with an Epson Expression A3 10000 XL scanner using the Debian Linux environment with the package Xsane (http://www.xsane.org). TRW was measured using the Image J software (http://rsbweb.nih.gov/ij/) with the plugin ObjectJ (http://simon.bio.uva.nl/objectj/index.html) specially developed for the measurement of TRW. A second crossdating was conducted using the measurement profiles determined by the BAR program of the DPL suite (Dendrochronological Program Library, http://www.ltrr.arizona.edu/pub/dpl/)considering 32-spline regression plots for visual comparison. This program helps to detect more detailed problems not previously detected

by the Yamaguchi method. Once the samples were visually crossdated, we analyzed the TRW data using the COFECHA program (Holmes, 1983).
To remove age trend and associated variance we used ARSTAN software (Cook 1985). We opted for a negative exponential curve for detrending and calculated ratios from negative exponential functions fitted to each individual TRW measurement series (Cook and Peters 1997,Düthornet al. 2013). We used the same settings for both species (Tab. 1) and considered the residual chronologies for further analyses (Fig. 1; Fig. 2).

Table 1: Chestnut and oak chronology characteristics.

Species	Samples	Period	Cofecha inter-series correlation	Mean TRW (mm)	Standard deviation	Lag-1 autocorrelation
C. sativa	12	1943-2003	0.582	3.40	1.926	0.677
Q. pyrenaica	23	1946-2010	0.540	0.25	0.139	0.650

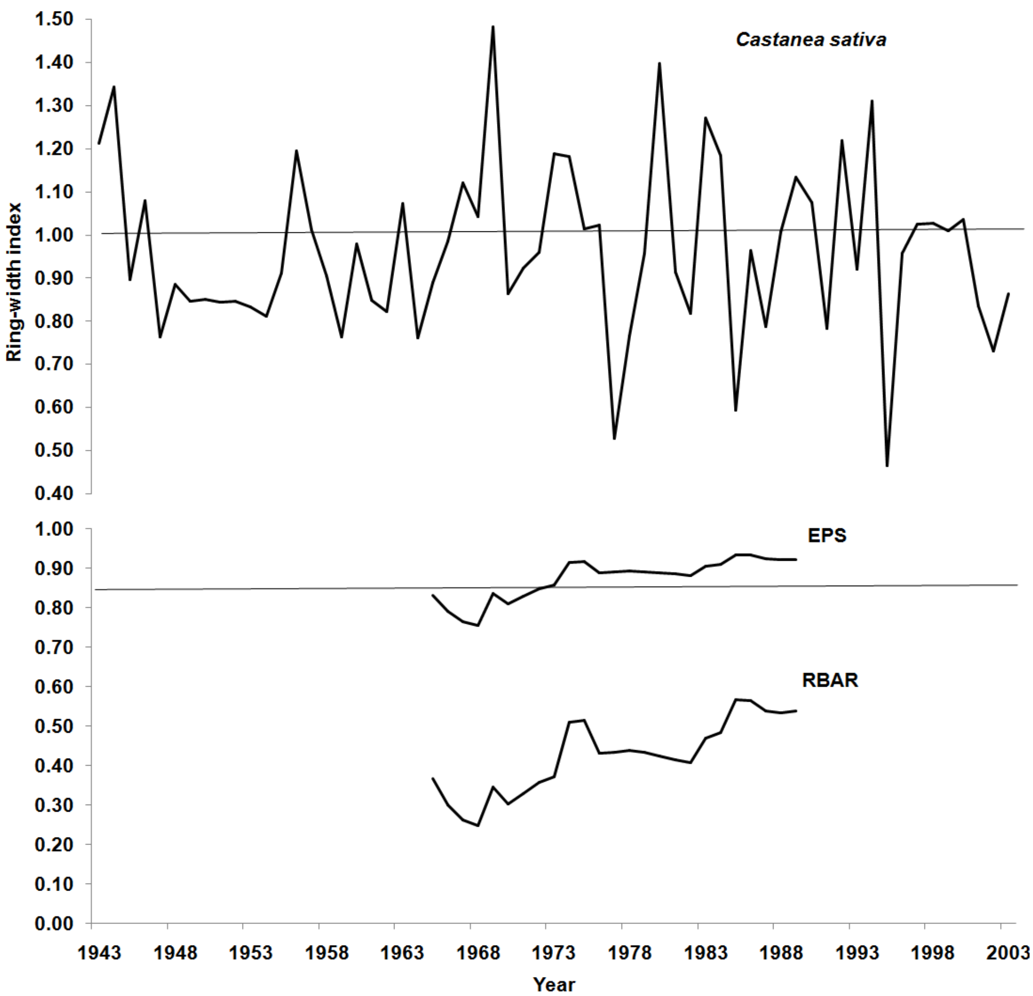

Figure 1: Castanea sativa residual chronology, and EPS and RBAR values.

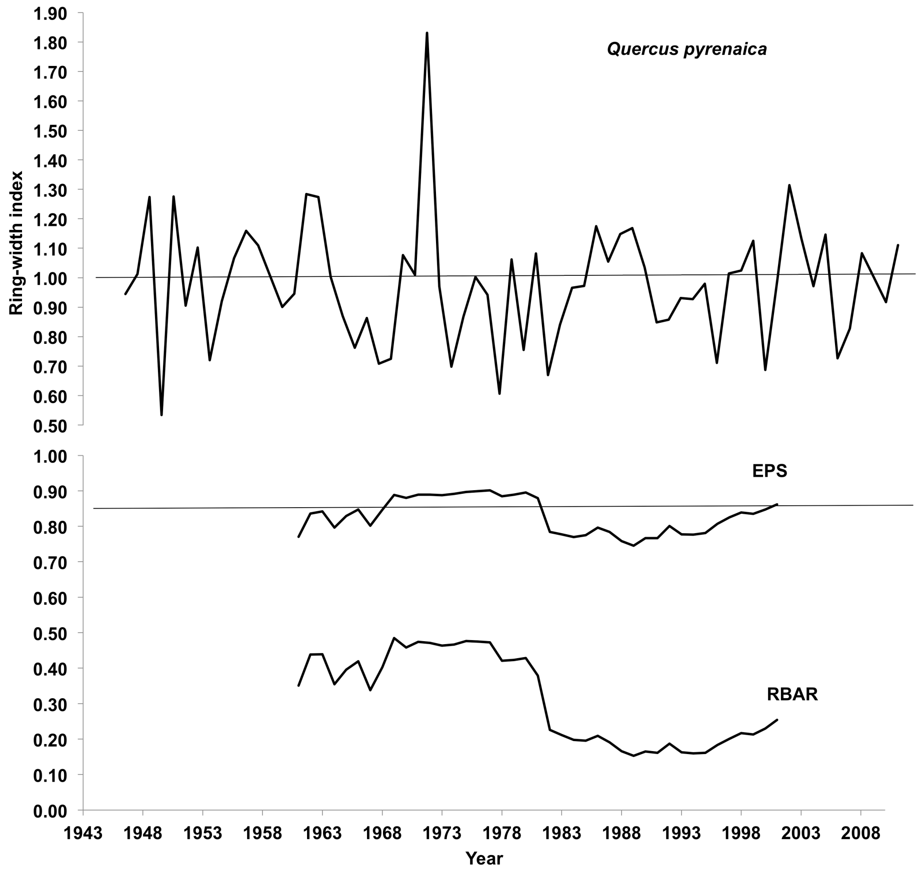

Figure 2: Quercus pyrenaicaresidual chronology, and EPS and RBAR values.

Due to SM is specific climatic conditions in contrast with the surrounding area (400 m altitude difference), selecting representative climate data had to be careful. The principal idea was to choose instrumental data from locations close to the sampling site to ensure unbiased analyses between TRW and monthly climate data. To assess and mitigate potential biases, we finally considered four different data sources (Fig. 3): (a) the Montánchez climate station with only monthly rainfall records, in 2 km distance from the sampling site and no significant altitudinal difference; (b) temperature and rainfall data from the Alcuéscar climate station, in 8.5 km distance and altitudinal difference of 280 m; (c) North Atlantic oscillation (NAO) station derived data (including the Lisbon observatory); and (d) gridded temperature, precipitation and Palmer Drought Severity Index (PDSI) data from KNMI (http://climexp.knmi.nl).

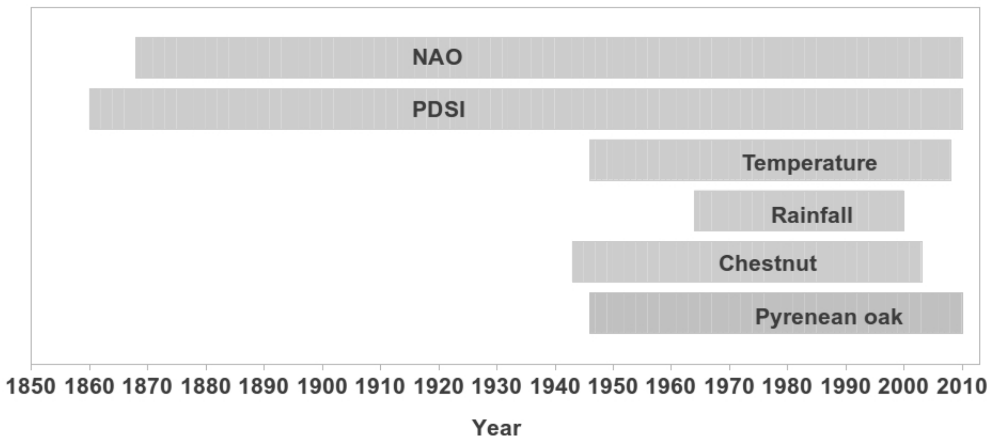

Figure 3: Periods covered by the instrumental temperature, rainfall, PDSI, and tree-ring data used in this study.

Pearson correlations were calculated to assess the association between TRW chronologies and (a) rainfall, (b) temperature, (c) PDSI, and (d) NAO data on a monthly, seasonal and annual basis. In order to account for potential memory effects previous year measurements were considered additionally. In addition to these calibration trials based on continuous time series, we extracted pointer years from both chronologies using a two standard deviation threshold, and analyzed the climatic parameters during these extreme years.

Results and discussion

As previous studies of this species in the region showed (Roig et al. 2009), chestnut can be correlated with the NAO index (Tab. 2). On the one hand, both species share a similar correlation to the spring rainfall, as an indicator of similar ecological niche. On the other hand, the negative correlations of the pyrenean oak with maximum April-August temperature could be explained because in southern Spain it is a species related to mountains, with an altitudinal gradient. Since SM is located close to its lower altitude distribution limit, high temperatures during April-August could restrict its growth (Pérez-Ramos & Marañón 2009). Chestnut, as a Mediterranean species, is better adapted to these temperatures if water availability is sufficient during the growth season, specifically in summer (JJA) period (Roiget al. 2009, Patón et al. 2006).

Table 2: Significant ($p < 0.01$) correlations between the chestnut and oak chronologies and climate variables over the 1946-2003 period.

Chronology	Mar-May rainfall	Apr-Aug max. temperature	Jun-Aug PDSI	Dec NAO
C. sativa	0.42			0.39
Q. pyrenaica	0.42	-0.40	-0.40	

In table 3 the results of the pointer years analysis are displayed. *Castanea sativa* showed strongly reduced growth in the climatically interesting years 1977 and 1995. 1977 was not a dry year in its annual mean rainfall, but for an important part of the growth season, namely the spring period (MAM), it was the driest throughout all recorded years with only 55 mm of accumulated rainfall (mean is 195 mm, see Tab. 4).

Table 3: Positive (+) and negative (-) pointer years exceeding +/- 2 standard deviations.

Pointer Years	*C. sativa*	*Q.pyrenaica*
1949		-
1969	+	
1971		+
1977	-	
1995	-	

Table 4: Castanea sativa pointer years and relationship with climate.

	Mar-May rainfall [mm]	Mar-May minimum temperature [ºC]
1977	55	-0.17
Climate average	195	2.95
	Annual rainfall [mm]	Mar-Aug maximum temperature [ºC]
1995	560	35.2
Climate average	770	32.8

At the same time 1977 is also the coldest year of the entire climate record of minimum mean spring temperatures. In this sense, we must notice that the temperature data is from Alcuéscar station with an altitude difference of 250 meters to the sample point, so in SM it could have been even colder. 1995 is one of the driest years of the 20th century in Spain, within a big drought period that started in 1991 (Llamas, 1997). Chestnut responds to a combination of the lack of rainfall - only 560 mm annual rainfall (770 mm is the annual mean) - and the highest spring+sumer (MAMJJA) maximum mean temperatures (Tab. 3). The residual chronology of *Quercus pyrenaica* is rather complacent in the years 1977 and 1995. However, this chronology marks positively in 1971, when the climatic data reveal the highest summer (JJA) precipitation and the highest summer positive values of PDSI. The years 1949 (*Quercus pyrenaica*) and 1969 (*Castanea sativa*) are not accompanied by significant climatic events (Tab. 3). We assume non-climatic effects dominated growth in those years.

Conclusions and outlook

In the wake of the correlations with climatic factors of both residual chronologies and the analysis of pointer years, it is not possible to explain the dynamics of Sierra de Montánchez chestnut forest by taking only a single climate parameter into account.

However, the analysis of pointer years indicates that the chestnut is more sensitive to various combinations of different climatic indicators such as low rainfall and extreme (cold and high) temperatures. In this sense, *Quercus pyrenaica*, as a mountain oak at this latitude, is perfectly adapted to the environment with different ecological strategies as higher root biomass accumulation (Ruiz-Peinado et al. 2012), better adapted leaves for drought and evapotranspiration than chestnut leaves, even marcescent leaves that protect the branches of herbivores (Svendsen & Claus 2001).

For future research it will be necessary to use multivariate data analysis to determine the exact weight of different factors that affect to the chestnut TRW. It is also necessary to apply techniques from forestry and ecology in combination with dendrochronology to better understand the dynamics of Sierra de Montánchez chestnut forest.

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