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ORIGINAL ARTICLE

Potential of oak tree-ring chronologies from Southern Portugal for climate reconstructions

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ABSTRACT

The present work reports a first attempt to assemble long tree-ring chronologies from Portugal potentially useful for climate reconstructions. Three oak species (*Quercus pyrenaica*, *Quercus faginea*, and *Quercus ilex*) were sampled at three sites in southern Portugal to obtain tree-ring chronologies. The longest tree ring series covers 173 years extending back to 1840. Our tree-ring records show, depending on the site, moderate-to-high correlations with precipitation in different seasons (from $r = 0.40$, $p < 0.01$, to 0.81, $p < 0.001$) and temporal stability in the growth/climate relationship for two sites. Calibration-verification trials confirm the reliability of climate/growth models for climatic reconstructions back to periods represented by tree-ring records from these two sites. Regional precipitation for Alentejo can be estimated for the following seasons: April through August (calibration $r^2 = 0.24$); September, from previous year, to July (calibration $r^2 = 0.65$). The results are a promising kick-off for Portuguese dendroclimatology, since they represent a significant breakthrough in the Mediterranean region, especially for Iberian Peninsula, where there is a considerable lack of dendroclimatic reconstructions. Further efforts to extend the tree-ring records back in time using subfossil material should be undertaken.

1. Introduction

The potential threats resulting from a changing climate have highlighted the importance of paleoclimatology studies in improving the current understanding of the climate system. The Earth's climate is progressively becoming warmer and this trend is projected to further enhance in future decades under anthropogenic forcing (IPCC, 2014a,b). The Mediterranean region is a climate change hotspot, as significant warming and drying are expected (Giorgi, 2006; Beniston et al., 2007; Gao and Giorgi, 2008; Nikulin et al., 2011; Diffenbaugh and Giorgi, 2012). Indeed, this region is at risk of experiencing the strongest alterations in ecosystem structure and composition, since it is already under vulnerable conditions (Cotillas et al., 2009; Sanchez-Salguero et al., 2010; Liñares and Tiscar, 2011; Pasho et al., 2011; Candel-Perez et al., 2012). Therefore, improving the current knowledge on past climate variability in Mediterranean climates is a top priority.

However, long and high quality dendroclimatic reconstructions for Mediterranean areas are scarce (Nicault et al., 2008). This is due to the extreme difficulties to obtain long tree-ring chronologies with strong and consistent climatic signals in Mediterranean-like climates, particularly when compared to central European climates (as reviewed by Cherubini et al., 2003). Efforts to overcome this drawback have increased considerably in the very recent years. Multicentennial-long tree-ring chronologies have been used to study temperature in the Pyrenees (Büntgen et al., 2010; Dorado-Liñán et al., 2012a), event years in central Spain (Genova, 2012), water-use efficiency in eastern Spain (Andreu-Hayles et al., 2011), drought variability in northwestern Africa (Esper et al., 2007; Touchan et al., 2011), Greece (Sarris et al., 2011) and in the Mediterranean Basin (Touchan et al., 2005; Nicault et al., 2008), as well as the North Atlantic Oscillation (NAO) index (Trouet et al., 2009). Although Touchan et al. (2011) used 48 oak trees from three sites

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(out of a total of 837 trees and 39 sites) most of the aforementioned studies used conifer species.

In the South of Portugal, southwestern Iberia, tree-rings of pine species have shown a good agreement with climatic variables (e.g. *Pinus pinea*, Campelo et al., 2007b, *Pinus pinaster*, Campelo et al., 2013; Vieira et al., 2010), but the oldest pines in this area are younger than 150 years. Oaks are potentially the oldest trees in mainland Portugal. Drought-resistant evergreen Mediterranean oak species (e.g. *Quercus ilex* and *Quercus suber*) are widely distributed in the south. Moving northwards, they are gradually replaced by marcescent sub-Mediterranean species (e.g. *Quercus faginea* and *Quercus pyrenaica*), and then by deciduous temperate species (e.g. *Quercus petraea* and *Quercus robur*), already in the Atlantic biogeographical zone (Benito-Garzon et al., 2008).

The longest tree-ring series for Portugal are ca. 250 year-old, from *Q. robur* growing in sub-humid microclimates in Central Portugal, but showing very low synchrony between samples (Santos et al., 2015). Nevertheless, low-frequency variability in some of these tree ring series is in agreement with long-term trends in spring precipitation. The remaining studies with oak species have mostly analyzed short tree-ring series (< 100 years). The climate/growth relationships are remarkably strong in young trees (< 30 yrs) of *Q. suber* (Leal et al., 2008), and *Q. ilex* (Campelo et al., 2007a, 2010) and in old trees (> 100 yrs) of *Q. ilex* (Campelo et al., 2009, Abrantes et al., 2013), even higher than those for temperate regions. However, these results were only possible to achieve by using stem cross sections resulting from authorized tree fellings. There are very strict regulations in the country concerning tree felling for these two species, particularly for *Q. suber*, which is a highly protected species because of its cork production. The transitional species, between Mediterranean and mesic oaks, such as *Q. pyrenaica* (Corcuera et al., 2002) and *Q. faginea* (Corcuera et al., 2004), because of their ring-porous wood and distinct rings, can be sampled through tree coring. This greatly improves the whole process of tree-ring chronology development, while still providing valuable climatic signals. Some studies successfully used cores from *Q. pyrenaica* to explore climatic control over this species growth in Iberia (Corcuera et al., 2006; Roig et al., 2009; Rozas et al., 2009; Gea-Izquierdo and Cañellas, 2014; González-González et al., 2014). To our knowledge, climate/growth relationships in *Q. faginea* were rarely studied using cores (e.g. Granda et al., 2014), despite its tree rings showing a response to climatic variables (Corcuera et al., 2004).

The present study is a first attempt to establish long tree-ring chronologies for dendroclimatic reconstructions in mainland Portugal. For that purpose, three oak species (*Q. pyrenaica, Q. faginea*, and *Q. ilex*) were sampled at three sites in southern Portugal. For each species: (a) the limitations in identifying and measuring tree rings; (b) the quality of the obtained chronologies, based on the strength of their common signal; and (c) their ability for dendroclimatic reconstructions, based on the strength and temporal stability of the climatic signals, are analyzed.

2. Material and methods

Tree-ring patterns in long-lived oaks, growing in Portugal, southwestern Iberia, and their suitability for dendroclimatic reconstructions are analyzed herein. The sampling took place at three sites in southern Portugal (Fig. 1), which are characterized by Mediterranean climates – types *Csa* (inland sites) and *Csb* (coastal site), according to the Köppen–Geiger classification, updated for the period 1950–2000 (Kottek et al., 2006).

At least 10 trees per site were sampled from three oak species making a total of 39 trees used for further analysis (Table 1). Tree ring samples were obtained as whole stem discs in the

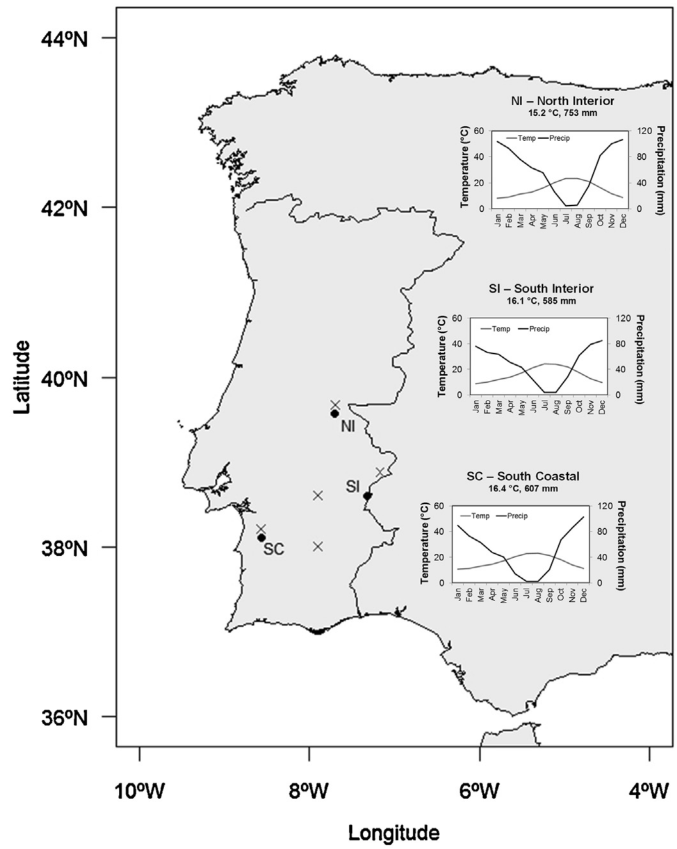

Fig. 1. Location of the study sites (NI: North Interior, SC: South Coastal, SI: South Interior), and respective ombrothermic diagrams for the closest meteorological stations (data from 1950 to 2000). The location of the meteorological stations used for the analysis of climate/growth relationships is also outlined (*x*).

case of *Q. ilex* as described by Campelo et al. (2009), or through tree coring (two cores per tree) in the case of *Q. pyrenaica* and *Q. faginea*. After standard sample surface preparation, tree-ring widths (and also latewood widths in the case of ring porous species, *Q. pyrenaica* and *Q. faginea*) were measured to the nearest 0.001 mm, using an increment measurement table, LINTAB Linear Table 560/2.5 mm, connected to a stereo microscope LEICA M80 and the software TSAP-Win Scientific. Tree rings were crossdated within and between trees by visual inspection of single curves plots. The results were checked and supported using correlation coefficients, Gleichläufigkeit values (Fritts, 1976), and Student's *t*-test across tree ring series. Using ARSTAN software (Cook and Holmes, 1986), cubic smoothing splines, with a 50% cut-off at a 60-year wavelength, were adjusted to the correctly dated series. Indexed series were obtained by dividing the original data through these curves. The effect of autocorrelation was removed and the resulting indexed series were averaged for each site using a bi-weight robust mean. The quality of the chronologies, concerning their strength of common signal and representativeness, was assessed through standard statistical indicators (Fritts, 1976; Wigley et al., 1984; Schweingruber et al., 1988; Cook and Kairiukstis, 1990): effective chronology signal (r_{eff}) and expressed population signal (EPS), using the R package *detrendeR* (Campelo et al., 2012).

Climate/growth relationships were analyzed with Pearson correlations between each site chronology and climatic variables (monthly precipitation and temperature averages from previous year September to current December). Data from the closest meteorological stations were used (Fig. 1): São Mamede for NI, and