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Species-specific weather response in the daily stem variation cycles of Mediterranean pine-oak mixed stands

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ABSTRACT

Climate change forecasts are particularly severe for the western Mediterranean Basin, where rising temperatures and decreased precipitation could increase the frequency of drought events. Understanding the specific weather drivers of radial variation in Mediterranean mixed forest stands will allow us to better predict the ecological and production alterations that may result from climate change. Here, we studied species differences in stem daily radial variation cycles and daily radial increment of Mediterranean pine-oak (*Pinus pinaster-Quercus pyrenaica*) mixed stands over three climatically contrasted years (2012-2014) at two sites with dissimilar drought conditions. Our aim was to uncover differences in the weather drivers of daily radial variation for the two co-existing species. High-resolution point dendrometers were installed in dominant oak and pine trees, so that daily radial variation cycles were analyzed. Linear mixed models were fitted to analyze species-specific response to weather. Air temperature leads to radial stem-size changes in daily variation cycles with different species responses. Precipitation increased daily radial variation and cycle duration in the same way for both species. Daily radial increment and number of cycles with increment phase during spring was mostly higher for pine than oak, and water availability was the most important control factor for the phase mentioned. Differences in species response to weather conditions may offset the usual low production of pure oak coppice Mediterranean stands and highlight the role of mixed forests as a possible adaptation strategy for climate change.

1. Introduction

Climate change may impact Mediterranean forests harshly (Dankers and Hiederer, 2008). Changes in extreme climatic conditions, such as more frequent and severe summer droughts, might affect the provision of goods and forest services (Hanewinkel et al., 2012). Climate change could influence biodiversity and ecosystem functioning through phenological alterations (Gordo and Sanz, 2009; Rossi et al., 2011), species-specific distribution range shifts (Peñuelas et al., 2007), changes in forest production (Linares and Camarero, 2012; Pretzsch et al., 2014) and subsequent changes in carbon storage (Vayreda et al., 2012).

Projected climate changes give urgency to the need for a better understanding of the effects of meteorological factors on growth in Mediterranean forests. Rising temperatures and drought events seem to be the key causes of tree decline in Mediterranean forests, despite tree acclimation to cope with climate change through phenological changes and increased water-use efficiency (Hartmann et al., 2015; Natalini et al., 2016; Peñuelas et al., 2011).

In this context, mixed forest stands could play an important role in preventing or reducing adverse changes. Mixed species stands might be more stable than monospecific ones, because of their greater resilience and resistance to biotic and abiotic factors (Guyot et al., 2016; Knoke et al., 2008; Pretzsch et al., 2013) and their higher temporal stability (Jucker et al., 2014; del Río et al., 2017). Mixtures could increase resistance and resilience in extreme drought conditions through complementary use of water resources based on species niche partitioning and alterations in water-use efficiency (Forrester, 2014). Although studies have shown contrasting results depending on species composition and site conditions, the positive effect of mixing species seems relevant to drought-prone sites (Grossiord et al., 2014; Forrester et al., 2016).

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Monitoring stem radial variations can provide insight into intra-annual stem dynamics and improve our understanding of climate impacts on tree physiology and growth processes (Deslauriers et al., 2007; Duchesne and Houle, 2011; Zweifel, 2016). Continuous or high-resolution dendrometer recordings provide valuable information on tree stem radial variation along with the possibility of studying tree response to environmental influences at a high temporal resolution (Siegmund et al., 2016). High-resolution dendrometers are commonly used for studying seasonal tree growth dynamics, uncovering the environmental parameters that drive tree growth, and monitoring aspects of tree water balance such as water use and drought stress (Van der Maaten et al., 2016; Zweifel, 2016; Zweifel et al., 2016). Consequently, automatic dendrometers are now widely used to provide high-resolution stem variation data on coniferous and broadleaf trees from boreal to tropical forests (Biondi and Rossi, 2015; Deslauriers et al., 2007; Duchesne and Houle, 2011). However, because these analyses often involve short observation periods, they do not accurately capture radial variations under contrasting weather conditions (Drew and Downes, 2009; King et al., 2013).

The handful of studies that have reported on seasonal variations in tree stem radius in Mediterranean areas mostly confirm the dominant role of temperature as the major constraint on radial increment in short time scales, and of precipitation effects in monthly scales (Camarero et al., 2010; Gutiérrez et al., 2011; Vieira et al., 2013). High-resolution stem diameter variation studies on mixed forests in this region are also infrequent. Sánchez-Costa et al., (2015) found contrasting growth and water use strategies in four co-occurring Mediterranean species, and Camarero et al., (2010) reported species-specific differences in xylogenesis patterns in mixed stands of *Juniperus thurifera* L., *Pinus halepensis* Mill., and *Pinus sylvestris* L. However, very little research is available concerning daily radial variation cycles in mixed stands, so remains unclear in the Mediterranean climate.

Recent studies have shown that the Mediterranean tree species *Pinus pinaster* Ait. and *Quercus pyrenaica* Willd are highly vulnerable to intense drought events (Gea-Izquierdo et al., 2013; Prieto-Recio et al., 2015). *P.pinaster* is one of the most common pine tree species in Spain and usually establishes spontaneous mixed stands with *Q.pyrenaica*. Consequently, forest management strategies during the second half of the twentieth century included re-introducing pine into oak coppice stands. These co-occurring species show different successional and phenological traits: light-demanding pine species are dominant in early successional stages, while deciduous oak is a moderately shade-tolerant tree that predominates in the late-successional stage. Studies of radial variation cycles focusing on these species are insufficient, with the exception of Vieira et al. (2013), who worked with *P.pinaster* for one year only (2010). A previous study by Aldea et al. (2017) on the same stands used in the current work, showed species differences in radial increment patterns and positive effects from heavy thinning.

For the research presented here, we used high-resolution dendrometer data to investigate species-specific tree responses to contrasted meteorological conditions in Mediterranean pine-oak mixed forest stands during the 2012–2014 period. The aims of the present study were 1) to show species differences in daily radial variation cycles, 2) to uncover species-specific weather responses in daily radial variation cycles and 3) to identify the weather variables that drove radial increment. We tested the hypotheses that (i) daily radial variation cycles varied according to seasons and species; (ii) differences were due to species responding differently to weather conditions and (iii) temperature and water availability were the main factors limiting radial increment, as expected in Mediterranean areas.

2. Materials and methods

2.1. Study sites

The study took place at two experimental sites with different drought conditions in central Spain: Lubia (Soria; 41° 39′ N, 2° 29′ W) and San Pablo de los Montes (Toledo; 39° 31′ N, 4° 16.6′W). The Lubia site was located at an altitude of 1134 m.a.s.l. on a continental plateau. It has a sub-humid continental Mediterranean climate with an annual rainfall of 512 ± 133 mm, of which 100 ± 49 mm falls during the summer drought period, between June and August (AEMET, 2016; Spanish State Meteorological Agency). Annual mean temperature is 10.0 ± 1.6 °C and the hottest month is July, with an average temperature of 18.9 ± 2.9 °C. Frost occurs from September to May.

The site at San Pablo de los Montes was established in the Montes de Toledo mountain range at 1,102 m.a.s.l. It has a continental Mediterranean climate, average rainfall of 469 ± 122 mm and a marked summer drought between June and August, with 49 ± 51 mm recorded rainfall (AEMET, 2016). Annual mean temperature is 12.9 ± 0.6 °C and the hottest month is July, with an average temperature of 23.9 ± 1.1 °C. Frost occurs from November to March.

The Walter-Lieth annual aridity index (WAI), defined as the quotient between the dry and wet season areas from climograms based on historical climate records (1981-2010; AEMET, 2016), was calculated using 'BIOdry' R package (Lara et al., 2013). The WAI index revealed drought differences between sites: WAI of 0.22 for Lubia and 0.65 for San Pablo de los Montes. Hereafter, we will refer to these sites as WAI-0.22 and WAI-0.65, respectively.The forest stands at both sites have similar origins: The initial oak coppice stands were completely harvested by clear-cutting during the 1970s, followed by afforestation with pines sown in rows. Oak coppice sprouts grew between the pine rows, and today the stand looks like a pine-oak even-aged mixed stand, though real cambial age differs between species

2.2. Stem radial variation and climatic measurements

Three dominant trees per species and site (twelve trees in total) were selected for installation of electronic point dendrometers. The pine trees chosen for sampling were 268.8 mm (standard deviation (sd) of 15.3 mm) in diameter at breast height and 11.2 m (0.7 m sd) high, while the oaks were 94.5 mm (7.3 mm sd) in diameter and 7.4 m (0.8 m sd) high. Besides, there were no significant differences in species diameter, height or age (for pine) between sites.

In autumn 2011, we installed electronic point dendrometers (Depfor, University of Huelva, details are available in Vázquez-Piqué et al., 2009) with a resolution of 1 μm in the selected trees to measure stem radial variation at breast height. The dead outermost layers of bark were carefully removed to avoid cambium damage and to eliminate hygroscopic influences from bark (shrinking and swelling due to change in air humidity) on dendrometer measurements. Data loggers were programmed to record measurements every 15 min for the entire 2012–2014 study period.

Site weather variables were continuously monitored using a variety of sensors. Air temperature, relative humidity and dew point were recorded at 15 min resolution using a data logger (HOBO U12 4-External Channel) placed at the WAI-0.22 site. A weather station (HOBO) was installed at the WAI-0.65 site to record air temperature, relative humidity, rainfall, solar radiation and wind speed. Additionally, temperature, precipitation and radiation records were compiled using hourly data from the AEMET automatic network stations (Lubia-Ceder 2044B and San Pablo de los Montes 3298X) located 6 km and 5 km from the WAI-0.22 and WAI-0.65 sites, respectively, to fill gaps in the climate information. Correlation between on site meteorological records and the network station was 0.978 and 0.969 for WAI-0.65 and WAI-0.22 sites, respectively. Records filled from network station data accounted for 9.2% (9.729 hourly records) and 29.6% (31.169 hourly records) of the total for WAI-0.65 and WAI-0.22, respectively. Mean vapor pressure deficit was also estimated from former weather measurements, and we applied indirect method described by Zweifel et al., (2005), to calculate tree water deficit by tree and year, using dendrometer measurements to quantify drought stress based on potential linear growth during periods