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High-elevation inter-site differences in Mount Smolikas tree-ring width data

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ABSTRACT

We present the longest high-elevation tree-ring width dataset in the Mediterranean reaching back to the 6th century CE. The network includes 101 living and 92 relict *Pinus heldreichii* Christ trees from four differently exposed sites in the 2100–2200 m a.s.l. elevation range of Mt. Smolikas in the Pindus Mountains in Greece. Though the sites were all sampled within a distance of < 1 km, inter-site correlations are surprisingly low ($r_{1550–2014}$ = 0.65–0.87), indicating site exposure might affect tree-ring formation. We here explore the consequence of exposure differences on the climate signals in an eastern Mediterranean treeline ecotone. Temporally stable growth/climate relationships reveal similar seasonal patterns among the four sites, but differences in signal strength. *P. heldreichii* growth at Mt. Smolikas is significantly controlled by temperature in April ($r_{1951–2014}$ = 0.33–0.50) and precipitation in June-July ($r_{1951–2014}$ = 0.23–0.42), which emphasizes the overall importance of an early growth onset and subsequent moisture conditions. The association between stem growth and April climate is strongest in the South-facing stand, supporting the significance of higher insolation rates at this thermally privileged site. Strongest summer precipitation signals are found in the NE-facing stand, where trees seem to benefit least from an early growth onset and where reduced meltwater supply may enhance the dependency on early summer precipitation. The significance of spring temperature on tree growth in all four sites constrains the emergence of a distinct summer precipitation signal in the Mt. Smolikas high elevation ecotone. Exploration of the site-specific influences on a new millennium-long tree-ring width dataset is an important step towards an improved understanding of long-term climate variability in the Eastern Mediterranean. Site-related differences in climate sensitivity in the high-elevation tree-ring network at Mt. Smolikas indicate that both temperature and precipitation during different seasons could potentially be reconstructed if distinct site exposures (S versus NE) are considered.

1. Introduction

Tree-ring width (TRW) chronologies are an important proxy for the reconstruction of climate variability over the past millennium (Esper et al., 2016). Information about past climate conditions and their implications for society improve our understanding of natural and anthropogenically driven climate variability (Büntgen et al., 2011). This is crucial in the development of future climate scenarios and the evaluation of potential social and environmental impacts of climate (Esper et al., 2004; Kovats et al., 2014). Continuous improvement of the spatial coverage by millennium-length TRW chronologies is needed to assess climate variability patterns and their association with forcings at regional (Köse et al., 2011; Seftigen et al., 2013; Trouet et al., 2012) and hemispheric scales (D'Arrigo et al., 2006; Esper et al., 2002; Schneider et al., 2015; Stoffel et al., 2015; Wilson et al., 2016).

P. heldreichii Christ (or Bosnian pine) is a Tertiary relict tree species, endemic to the high mountains of the Balkans, and is abundant in northern Greece, western Bulgaria, Bosnia-Herzegovina, and Albania (Brandes, 2007). The species survives in very old stands with individuals of millennial age (Konter et al., 2017) demonstrating the potential of these sites to contribute to high-resolution paleoclimate reconstruction. The wood of *P. heldreichii* is very resinous and consequently resistant to decay and decomposition. This characteristic is beneficial for preserving material from fallen trees, especially in remote areas of the timberline ecotone (Brandes, 2007).

Numerous Bosnian pine chronologies have been developed from

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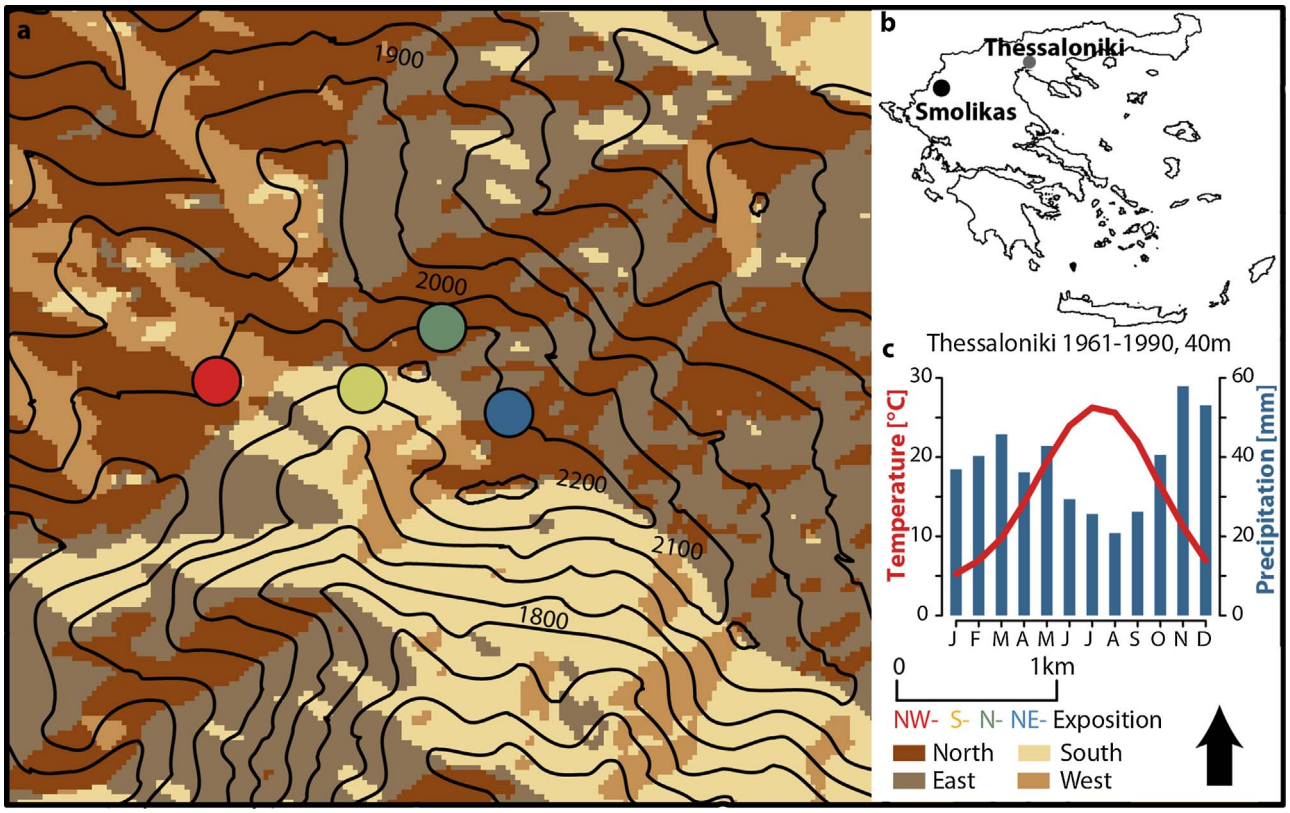

Fig. 1. a Contour and site exposure map of the study region and position of the sampling sites; **b** map of Greece indicating the research area and the instrumental station, **c** Climate diagram of the meteorological station in Thessaloniki (40 m a.s.l., 1961–1990).

collections in various areas of the species' range. These extant chronologies have two common features: they are typically very long, and the climate signal from their TRW measurements is weak (maximum $r_{1901-2002} = -0.29$ with June-July temperature in Seim et al. (2012); $r_{1925-2000} = 0.29$ with April Temperature in Todaro et al. (2007); $r_{1934-2004} = 0.38$ with previous August Precipitation, and $r_{1985-1992} = \sim$-0.3 with June temperature in Panayotov et al. (2010)). The species is resistant to a rough mountain climate and can tolerate harsh winters as well as a certain degree of summer drought. Therefore, the existence of the pure, zonal *P. heldreichii*-stands in northern Greece is explained by the seasonal extremes of a low latitude mountain climate (Brandes, 2007).

Theories explaining the low climate sensitivity are diverse and encompass anthropogenic activity, the remoteness of meteorological stations, and mixed climate controls (Panayotov et al., 2010; Seim et al., 2012; Todaro et al., 2007). However, most previous studies did not consider site-specific ecological constraints as influences on climate signals (Holland and Steyn, 1975; Schweingruber, 1996). Near to the Greek border with Albania, Mount Smolikas (2637 m a.s.l.) crowns the mountain range of the northern Pindus mountains at 40°05′N/20°55′E (Fig. 1a and b). The sites in this study are situated around an eastern foothill of Mt. Smolikas and differ in exposure only (Fig. 1b). Slope aspect alters the amount of received solar radiation and length of insolation period, thus creating a range of microclimates on a small spatial scale (Gallardo-Cruz et al., 2009; Hartl-Meier et al., 2014; Hartl-Meier et al., 2015; Holland and Steyn, 1975; Urban et al., 2000). Insolation controls evapotranspiration, soil and air temperature, air humidity, soil moisture, and the duration of the growing period that in turn affects the species composition and biomass production (Måren et al., 2015; Paudel and Vetaas, 2014; Pook and Moore, 1966). In the Mediterranean, south-facing slopes receive the most sunlight, which supports evapotranspiration and results in drought stress for trees, whereas north-facing slopes retrain more humidity and favor growth (Sternberg and Shoshany, 2001).

In this study, we explore the effect of slope exposure on tree growth and the impact on potentially varying climate signals by calibrating the chronologies of four differently exposed, high elevation *P. heldreichii* sites against regional instrumental temperature, precipitation, and drought data. We introduce a preliminary millennium-length TRW dataset and evaluate its potential and limitations for establishing a climate reconstruction.

2. Material and methods

2.1. Geographical settings and sampling design

In northern Greece, *P. heldreichii* is native to the upper oro-mediterranean vegetation zone and appears first at ca. 1.000 m a.s.l. in mixed forests with *Fagus sylvatica* L., *Pinus nigra* J.F. Arnold, and *Abies borisii-regis* Mattf. Between 1.500-2.300 m a.s.l., *P. heldreichii* forms pure stands to the timberline, with dwarfed specimens reaching 2.600 m a.s.l. on Mt. Olympus (Brandes, 2007). The southern distribution limit of the species is near the village Metsovon, in the Pindus mountains, at 39°40′ N. On Mt. Smolikas, the zone of pure *P. heldreichii* stands starts at 1.300-1.500 m a.s.l. and transforms into an open timberline ecotone at 1.900-2.400 m a.s.l. (Brandes, 2007). Anthropogenic impacts are presently constrained to pastoral farming. However, the name Mt. Smolikas, originating from the Slavic word "Smola" (engl. tar), points to a much greater economic importance of the area in the past, when the *P. heldreichii* resins were extracted for tar production (Meiggs, 1982). Geologically the higher areas of the mountain are formed by serpentine, a dry bedrock poor in nutrients, but not karstified or fissured (Hughes et al., 2006; Stevanovic et al., 2003). *P. heldreichii* grows on dry substrate, such as limestone and serpentine rocks.

Between 2011 and 2015, 101 living and 92 dead *P. heldreichii* trees were sampled in this timberline ecotone in 2100–2200 m a.s.l. at four