RESPONSES TO CLIMATE AND DROUGHT OF TREE RING FEATURES IN *ABIES BORISII-REGIS* FORESTS ALONG AN ALTITUDINAL GRADIENT IN SOUTH-EAST OF ALBANIA

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Abstract

In this study, we investigated the impact of climatic drivers (temperature, precipitation) and drought, using the Standardized Precipitation Evapotranspiration Index (SPEI) calculated at different time scales (1–12 months), on earlywood (EW), latewood (LW) and tree ring width (TRW) growth of *Abies borisii-regis* mountain forests in south-eastern Albania, by means of correlation analysis. A Principal Component Analysis (PCA) was applied to quantify the temporal patterns of radial growth chronologies. We found that EW growth was positively correlated with precipitation in June and July, while the LW growth was enhanced by the previous October, current June, July precipitation. The TRW showed similar responses to precipitation at all sites as the LW did. High summer temperatures constrained radial growth components (EW, LW, TRW) in *A. borisii-regis* forests at all sites. The PCA identified two patterns of radial growth representing growth variability in upper, lower (PC1) and middle site (PC2) respectively. All the growth components showed the highest response to drought at short time scales (< 4 months) during July, August and September, despite significant associations were found at higher time scales. The highest impact of drought on growth was observed on the LW growth, particularly at mid elevation site. The findings of this study should be useful to understand forest responses to climate change, including an increasing frequency of severe droughts, and to adapt appropriate management strategies to mitigate the impact of drought on tree growth.

Keywords: climate, drought, radial growth, Abies borisii-regis, SPEI.

Introduction

Climate observations prove the existence of a global warming trend in the Mediterranean basin associated with a decrease in precipitation together with enhanced temperature and evapotranspiration leading to an increase in the frequency and severity of drought events (IPCC, 2007; Räisänen et al., 2004; Sterl et al., 2008). These extreme climatic episodes are expected to be intensified in the future under warmer conditions (Giorgi and Lionello, 2008; Räisänen et al., 2004; Rozas et al., 2009) This is particularly the case of Albania, where climate change scenarios predict a large temperature rise (+5°C) and precipitation decrease (-25%) by the end of the 21-st century (IPCC, 2007). These values are expected to vary among seasons and different parts of the country, indicating severe drought events particularly during summer months in the north and north-east of Albania (Bruci, 2007). Under these climatic conditions the growth and distribution of tree species will be modified through growth decline and mortality episodes, mostly in drought-prone ecosystems (Martınez-Vilalta and Piñol, 2002). Mediterranean mountain conifer forests are expected to be very sensitive to climate warming because temperature rise could affect wood production by increasing aridity through enhanced evapotranspiration and water loss (Camarero and Gutiérrez, 2007; Linares and Tíscar, 2010; Macias et al., 2006). However, temperature variability may not be the main factor driving forests growth in these areas; precipitation may also play a significant role as it interacts with temperature to determine water availability for tree growth. Increased temperature commonly has a positive effect on tree growth but the impact can be negative if there is no corresponding increase in precipitation, as water stress may occur. Several authors indicated a high impact of temperature on tree growth in the Mediterranean region during the second half of the 20th century suggesting that climate conditions limited tree growth as a consequence of induced temperature-related water stress (Andreu et al., 2007; Martínez-Vilalta et al., 2008). Such impacts change significantly with elevation and site conditions which cause important variations to climatic conditions and growth characteristics of trees (Fritts, 1976; Orwig and Abrams, 1997; Rolland et al., 1999).While various studies have analyzed the climate influence on tree growth in the Mediterranean coniferous forests (Camarero et al., 2011; Macias et al., 2006; Tardif et al., 2003) much less attention has been given to the related tree growth sensitivity to accumulated drought conditions which are quantified by means of multi-scalar drought indices. This is crucial because lags between water shortages and growth can appear as a function of different anatomical and physiological adjustments of trees to cope with drought stress but also in response to drought severity, duration, and to the season in which water deficit occurs (Pasho et al., 2011). All these mechanisms, either isolated or acting synergistically, can challenge the identification of drought impacts on tree growth. Among the existing drought indices (Heim, 2002; Mishra and Singh, 2010) only the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evaporation Index (SPEI) can be obtained at different time scales and allow the determination of duration, magnitude and intensity of droughts. The SPI is calculated using only precipitation

data (McKee et al., 1993) while the SPEI includes both precipitation and temperature influence on droughts by means of the evapotranspiration processes (Vicente-Serrano et al., 2010a). Although precipitation is the main variable explaining the frequency, duration and severity of droughts (Chang and Kleopa, 1991; Heim, 2002), recent studies have shown that the effect of temperature (or evapotranspiration) is significant (Hu and Willson, 2000), particularly under global warming scenarios (Dubrovsky et al., 2009).The increasing climate warming associated with enhancement of drought stress, is expected to affect the growth, productivity and in long term, the present distribution of Mediterranean firs (Aussenac, 2002; Macias et al., 2006; Linares et al., 2011). This could be particularly the case of *Abies borisii-regis* Mattf. which is a highly water demanding species (Aussenac, 2002). *Abies borisii-regis* is a taxon regarded as a natural hybrid between *A. alba* and *A. cephalonica,* and is found only in the Balkan Peninsula from southern Albania to the northern Greece, Macedonia and Bulgaria region (Chater, 1964; Delcheva et al., 2010; Esteban et al., 2009; Scaltsoyiannes et al., 1999). No studies have considered this geographically restricted species to simultaneously evaluate its response to climatic variability and accumulated drought stress. Consequently, it was hypothesized that the radial growth of *Abies borisii-regis* will be vulnerable to warming induced drought stress accumulated during summer months and such impact will show a certain variation along an altitudinal gradient. Moreover, it was hypothesized that short-term water shortages will have a more pronounced effect on latewood (LW) than earlywood (EW) growth of *A. borisii-regis* since the EW growth is almost finished when water deficit starts in the late summer. Therefore, this study was designed to quantify the (i) temporal variability of radial growth (EW, LW, tree ring width (TRW)) in *A. borisii-regis* forests along an altitudinal gradient in south-east of Albania; (ii) impacts of climate and drought assessed at different time scales on growth of this tree species.

Materials and methods

Study area

The study area comprises three sites of *A. borisii-regis* forests distributed along an altitudinal gradient in the National Park "Bredhi i Hotovës'', south-east of Albania (Figure 1).
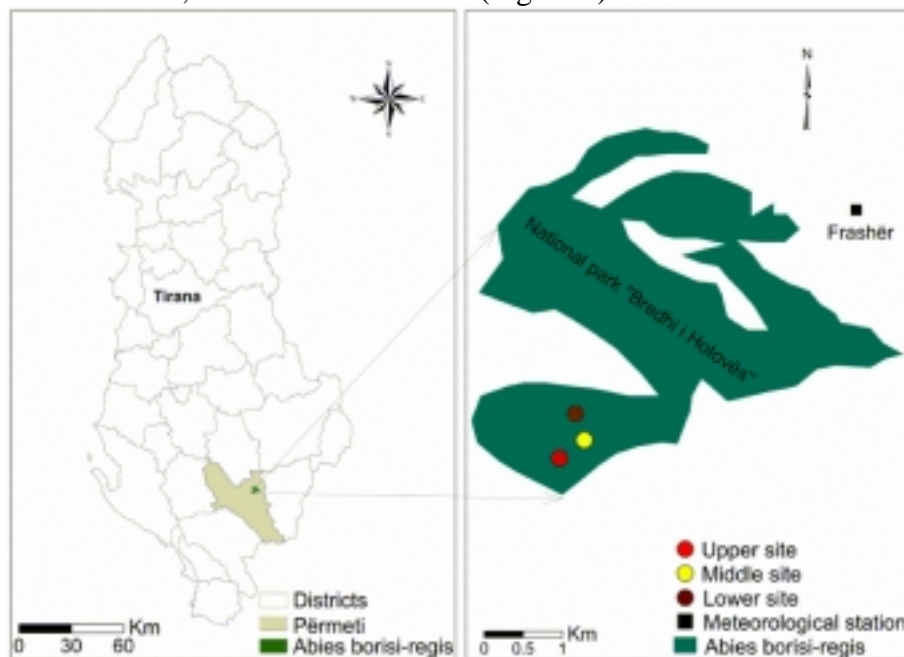

Figure 1. *Distribution of the study area (left part) in Permeti region (south-east of Albania), the location of study sites (in circles) and the meteorological station (black square) in the village of Frashër (right area).*

The area is characterized by pre-mountainous and mountainous Mediterranean climate with mean annual temperature of 12.3° and total annual precipitation of 1437.1 mm (Table 1). The soil types are brown and mostly grey dark which have good physical characteristics (high organic matter, rich of nutrients, etc) for the vegetation growth (Zdruli and Lushaj, 2000). *A. borisii-regis* is the dominant tree species in the study area occupying 1200 ha. Other co-living tree species (less than 5 % of the area) are *Acer obtusatum*, *Acer campestre*,

Quercus cerris, *Quercus frainetto*, etc. The understory vegetation is composed of shrubs (*Corryllus avellana*, *Carpinus orientalis*, *Cornus mass*, *Sorbus torminalis*, etc) and herbaceous species (*Geranium robertianum*, *Sanimla sp.*, *Lactuca sp.*, *Galium sp*, etc).

Climatic data and drought index calculation
To quantify the climatic variability in the study area we used the data from a local meteorological station located in a similar elevation and a distance less than 5 km from the sampled sites (Figure 1). From this station, monthly data of mean temperature and total precipitation were collected for the period 1950–2009 and used to quantify the climatic variability in the study area. To compare with the de-trended forest growth series and to avoid the possibility that climate trends could distort potential relationships, the trend in precipitation and temperature data was removed by fitting a linear trend in each series. The SPEI was calculated based on a monthly climatic water balance (precipitation minus potential evapotranspiration), which is adjusted using a 3-parameter log–logistic distribution to take into account common negative values. The values are accumulated to different time scales and converted to standard deviations with respect to average values. The complete methodology is described by (Vicente-Serrano et al., 2010b). The trend in each of the SPEI time series was removed by fitting a linear evolution in each monthly series at the different time scales.

Dendrochronological methods
In early summer 2011, at three sampling sites we randomly selected more than 18 dominant living healthy trees of *A. borisii-regis*, separated by at least 5 m from each other and measured their diameter at breast height (Table 1).

Table 1. *Characteristics of the studied sites*

Site (code)	Latitude (N)	Longitude (E)	Elevation (m)	Mean annual temperature (°C)	Total annual precipitation (mm)
High (H)	40° 20' 17"	20° 22' 57"	1361	12.3	1437.1
Mid (M)	40° 20' 35"	20° 23' 58"	1144	12.3	1437.1
Low (L)	40° 20' 44"	20° 22' 57"	1058	12.3	1437.1

Climatic data are annual values and were obtained from a meteorological stations located at similar elevation and at less than 5 km from the closest sampling site.

The studied sites were selected to capture most of the climatically mediated growth variability of *A. borisii-regis* forests in south-east of Albania. Two radial cores per tree in opposite directions were removed at 1.3 m height using a Pressler increment borer. The cores were prepared following standard dendrochronological methods (Fritts, 1976). They were air-dried, mounted and sanded with sandpaper of progressively finer grades until EW, LW and TRW were clearly visible with a binocular microscope. All samples were visually cross-dated and the EW, LW and TRW widths were measured separately to a precision of 0.001mm and accuracy of ±0.0003mm, using a LINTAB measuring device (Rinntech, Heidelberg, Germany). We distinguished EW and LW based on the visual contrast in color, where LW is dense, deep-colored, presenting a sharp contrast to the soft, straw-colored EW. Cross-dating was evaluated using the COFECHA program (Holmes, 1983). To retain the high-frequency variability of growth, each series was double-detrended using firstly a negative exponential function and secondly a spline function with a 50 % frequency response of 32 years. Standardization involved transforming the measured values into a dimensionless index by dividing the raw values by the expected values given by the spline function. Autoregressive modeling was carried out on each series to remove temporal autocorrelation. The indexed residual series of all trees within each site were then averaged using a biweight robust mean to obtain mean site residual chronologies. We used the program ARSTAN (Cook, 1985) to obtain the residual site chronologies of EW, LW and TRW width which were used in all subsequent analyses. The quality of the chronology data was evaluated using several dendrochronological statistics (Briffa and Jones, 1990): the mean width and standard deviation (SD) of the EW, LW and TRW raw width series; the first-order autocorrelation (AC1) of these raw series, which measures the year-to-year persistence; the mean sensitivity

(MSx) of the residual series, which quantifies the relative change in width among consecutive years; the expressed population signal (EPS) of residual series, which indicates to what extent the sample size is representative of a theoretical infinite population; and the mean correlation (Rbar) among individual residual series within each site. The common period 1950-2009 was selected because all site residual chronologies showed EPS values above the 0.85 threshold, which is widely used in dendrochronological studies (Wigley et al., 1984).

Statistical analysis
The climate–growth relationships were quantified using the residual EW, LW and TRW chronologies of each site and the detrended climate series of monthly mean temperatures and total precipitation. Correlation analyses, using the Pearson coefficient, were computed over the common period 1950–2009 using a 14-month window from September of the year prior to growth (year t-1) until October of the year of tree-ring formation (year t). Correlation analyses were also performed between EW, LW and TRW chronologies and the detrended monthly SPEI series representing drought severity for the period 1950–2009 at each sampled site. We also obtained the percentage of EW, LW and TRW growth variability explained by climate (mean monthly temperature and total monthly precipitation) in each site (R^2adj, adjusted R^2) through multiple linear regressions, based on a stepwise forward selection of significant variables (P 0.05), calculated between EW, LW, TRW indices and the local monthly climatic data. The temporal patterns of EW, LW and TRW residual chronologies for the period 1950–2009 were quantified using principal component analysis (PCA). The PCA was performed on a covariance matrix calculated among the chronologies (Legendre and Legendre, 2008). The number of components was selected using the criterion of an eigenvalue > 1, and the components were rotated (Varimax) to redistribute the final explained variance, and to obtain more stable and robust spatial patterns (Garfin, 1998; Richman, 1986). To detect the climatic factors which potentially affect the growth patterns as revealed by the PCA, correlation analysis were carried out between the PC loadings and the monthly mean temperatures and total precipitation.

Results

Chronologies variability
The mean width values of EW, LW and TRW varied among sites (EW, 1.28–1.70 mm; LW, 0.55–0.75 mm; TRW, 1.83–2.43 mm) (Table 2).

Table 2. *Dendrochronological statistics of earlywood (EW), latewood (LW) and tree ring width (TRW) of A. borisii-regis chronologies for the common period 1950–2009*

Site	Growth variables	Trees (radii)	Period	MW (mm)	SD (mm)	AC1	MSx	Rbar	EPS	R^2 adj (%)	PCA	
											PC1	PC2
H	EW	22 (31)	1900-2010	1.55	0.72	0.76	0.24	0.21	0.88	11.8	0.84	0.29
	LW	22 (31)	1900-2010	0.75	0.40	0.64	0.24	0.27	0.91	36.3	0.39	0.76
	TRW	22 (31)	1900-2010	2.30	1.03	0.77	0.22	0.26	0.91	38.8	0.74	0.56
M	EW	36 (54)	1874-2010	1.70	0.89	0.76	0.26	0.25	0.94	19.6	0.53	0.69
	LW	36 (54)	1874-2010	0.74	0.48	0.59	0.26	0.29	0.95	33.9	0.19	0.97
	TRW	36 (54)	1874-2010	2.43	1.26	0.76	0.26	0.30	0.95	28.1	0.42	0.86
L	EW	18 (28)	1893-2010	1.28	0.49	0.70	0.22	0.28	0.91	26.9	0.90	0.23

LW	18 (28)	1893-2010	0.55	0.26	0.60	0.22	0.26	0.90	28.7	0.68	0.56
TRW	18 (28)	1893-2010	1.83	0.68	0.72	0.20	0.31	0.92	30.6	0.86	0.40

Statistics: Raw-data series: MW, mean width; SD, standard deviation of width, AC1, first-order autocorrelation. Residual series: MSx, mean sensitivity; Rbar, mean interseries correlation; EPS, expressed population signal; R^2adj, adjusted R^2 obtained relating monthly climatic variables and EW, LW, TRW residual chronologies through stepwise linear regressions; PC1, PC2 loadings of each variable (EW, LW, TRW) in the first and second principal component.

The average values of AC1 were higher for TRW (AC1 = 0.75) than EW (AC1 = 0.74) and LW (AC1 = 0.61) while the MSx showed greater average values in EW and LW (MSx = 0.24) than TRW (MSx = 0.23). Considering the Rbar and EPS values, they appeared to be higher for the TRW (Rbar = 0.29, EPS = 0.93) than LW (Rbar = 0.27, EPS = 0.92) and EW (Rbar = 0.25, EPS = 0.91). Therefore, TRW chronologies showed a greater year-to-year persistence (AC1) and a higher common signal (Rbar, EPS) than EW and LW chronologies whereas the later (EW, LW) had a higher relative change between consecutive years (MSx) than TRW series. The higher values of the above chronologies statistics were noticed in the middle site followed by the upper and lower site. The percentage of LW growth variability related with that of EW (r^2, %) was higher in the middle site (61.4%) followed by the lower (42.6%) and upper (27.8%) site respectively. On the average, 44 % of LW width variability was related to EW width variability. We observed high-frequency growth patterns for EW, LW and TRW width series with growth reductions in 1890, 1907, 1951, 1989 and 2003 (Figure 2). The periods characterized by substantial increase in EW, LW and TRW width corresponded to the years 1905, 1928, 1940, 1965, 1997 and 2004. These sharp growth decreases and increases were higher in the middle site and coincided with dry (SPI < 0) and wet conditions (SPI > 0), respectively.
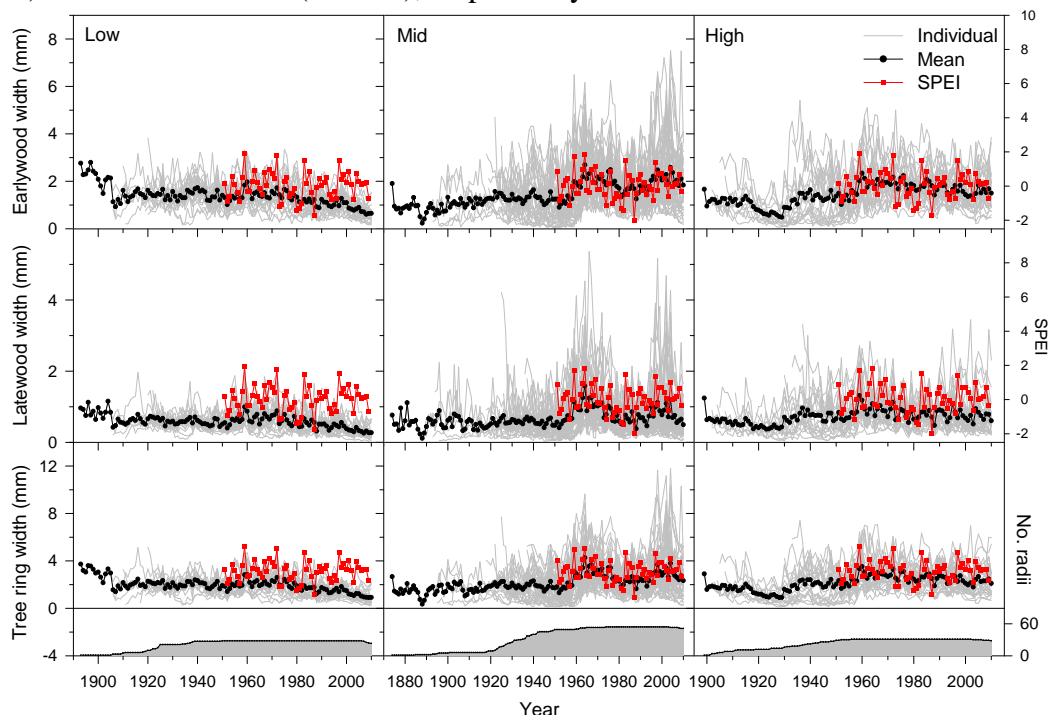

Figure 2. Raw radial growth chronologies of earlywood (EW), latewood (LW) and tree ring width (TRW) (gray lines) for the A. borisii-regis sampled sites in SE of Albania and the overall mean for each variable (black lines). The lower part of the graph shows the number of radii in particular years. Red lines show the evolution of the drought index (SPEI) at time scales of 2-3 months in July and August, the scale at which EW, LW and TRW growth series responded strongly to the SPEI drought index. Note that positive and negative SPEI values indicate wet (high EW, LW, TRW indices) and dry conditions (low EW, LW, TRW indices), respectively.

Climate – growth relationships

On average the proportion of growth variance explained by climate was generally higher for LW (33%) and RW (32.5 %) than EW (19.4 %), and varied among sites (Table 2). Correlation analysis revealed positive responses of EW growth at the middle site to current June, July precipitation and only to July rainfall at the lower site (Figure 3). The LW growth at the upper site was enhanced by the previous October, current June and July precipitation whereas at the middle site it showed positive relationship with March, June and July precipitation of the current growth year. At the lower site, only July precipitation affected significantly and positively the LW growth. The TRW showed similar responses to precipitation at all sites as the LW did. Considering the temperature impact on tree growth, the EW growth was enhanced by the previous December temperature and negatively affected by high summer temperature, particularly at the upper site. A similar pattern was also observed in the case of LW and TRW. The middle and lower site showed some negative association with June and July temperatures, especially for the LW growth. The PCA analysis revealed two main principal components (PC) for the EW, LW and TRW which accounted for the 84% (PC1 43%, PC2 41%) of the radial growth variance, respectively. According to the loadings of PC1 and PC2 (Table 2), there were found two main patterns of radial growth variability associated with upper, lower sites (PC1) and middle site (PC2) respectively.
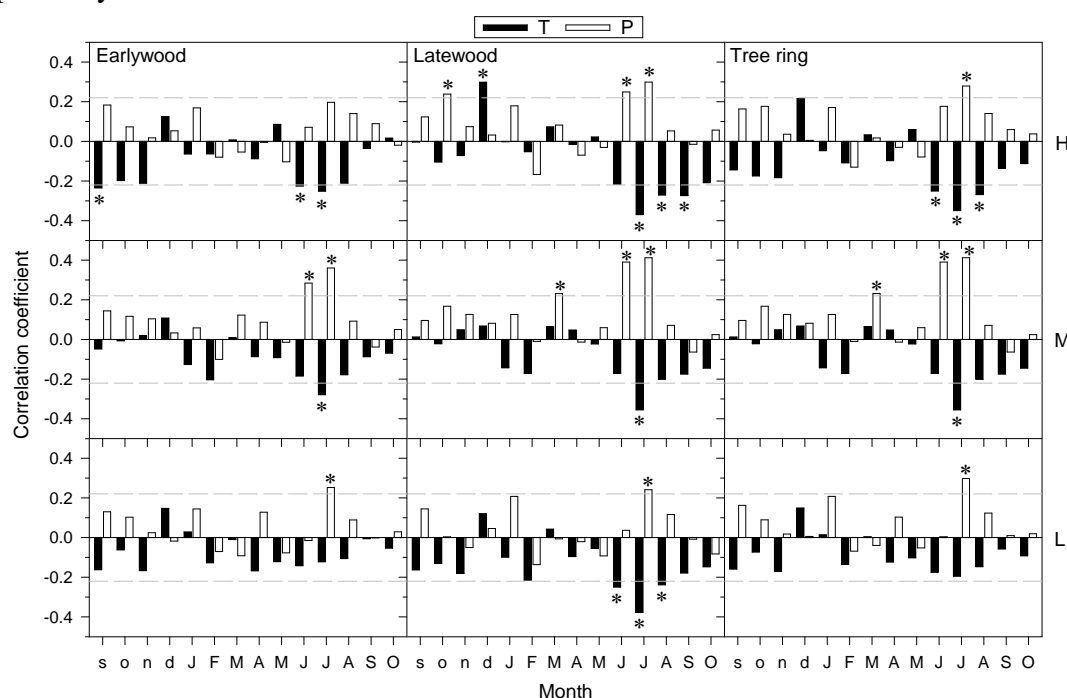

Figure 3. *Correlation coefficients calculated between earlywood (EW), latewood (LW) and tree ring width (TRW) chronologies of the three studied sites and monthly climatic variables (mean temperature and total precipitation). Growth is related with climate data from the previous September to current October of EW, LW and TRW formation. The significance level (P < 0.05) is indicated by dashed horizontal lines.*

The first pattern (PC1) did not show any significant relationship with climate while the second one (PC2) was positively correlated with March, June and July precipitation and negatively with July temperatures (Table 3).

Table 3. *Pearson correlation of the main principal components (PC) of earlywood (EW), latewood (LW) and tree ring width (TRW) with climatic variables (monthly mean temperatures and total precipitation).*

Principal components	Climate variables	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	No
PC 1	P	0.17	-0.13	-0.18	0.08	-0.15	-0.15	0.13	0.12	0.06	-0.02	-0
	T	0.05	-0.08	-0.03	-0.18	-0.05	-0.17	-0.11	-0.13	0.03	-0.01	0.0

PC 2	P	0.09	-0.03	**0.26**	-0.05	0.06	**0.44**	**0.37**	0.03	-0.08	0.04	0.0
	T	-0.12	-0.14	0.04	0.09	0.00	-0.13	**-0.36**	-0.19	-0.17	-0.15	-0

Numbers in bold indicate significant correlations (P < 0.05)

Drought – growth relationships

The correlations between EW, LW, TRW growth indices and the SPEI reached maximum values at similar time scales (< 4 months), despite significant associations (although weaker) were found at higher time scales (Figure 4). The strongest impact of drought on EW growth (r = 0.48, p < 0.05) was observed in July-August, whereas LW responded strongly (r = 0.59, p < 0.05) to SPEI August-September values. The TRW was significantly affected by drought (r = 0.46, p < 0.05) during July-September months. We also detected a certain variability among sites in terms of tree growth responses to drought. The strongest response of EW, LW, TRW growth to drought was found in the middle site whereas the upper and lower sites were less affected by drought.
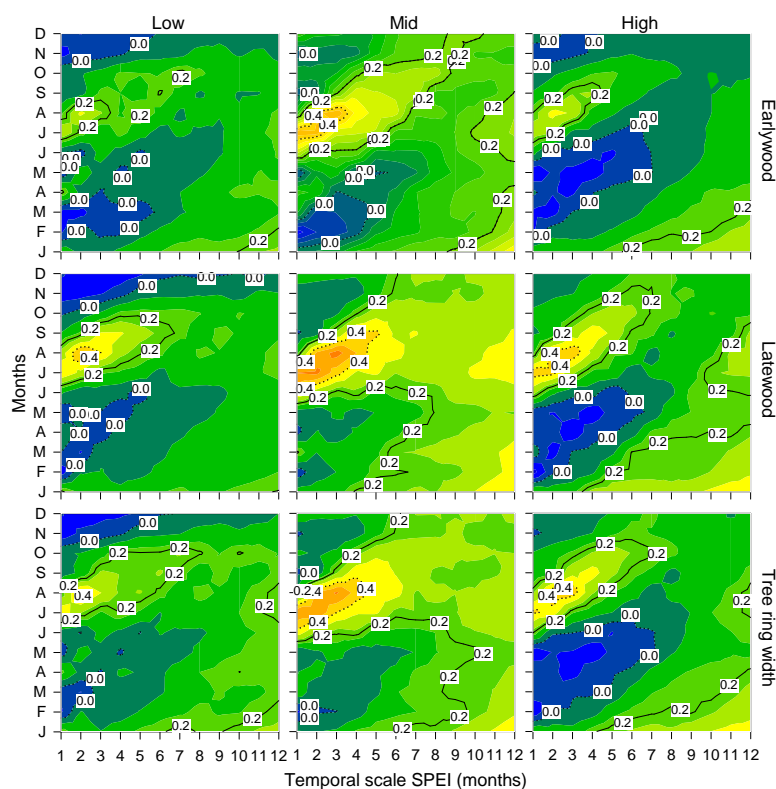

Figure 4. *Correlation coefficients between earlywood (EW), latewood (LW) and tree ring width (TRW) chronologies and the SPEI drought index calculated at different time scales (1–12 months) from January up to December, for the three study sites. Bold lines frame significant correlations (P < 0.05).*

Discussion

This research was focused on the radial growth response of *A. borisii-regis* forests to climatic variability and drought stress. To the best of our knowledge, this is the first investigation exploring the relationships between tree growth in this specie and climate (precipitation, temperature) including also a drought index calculated at cumulative time scales. Climatic factors significantly impacted the radial growth in *A. borisii-regis*, particularly LW production, as observed by the relatively high values of adjusted R^2. The EW and LW series presented a strong within tree-ring correlation, especially at the middle site, indicating a dependence of LW formation on previous EW growth. In general, the EW, LW, TRW chronologies of the three sites showed a strong common signal related to climatic factors, mostly in response to summer temperature and rainfall amounts. This is particularly the case of LW, whose formation usually peaks in late summer early autumn. The negative effect of September temperature on LW growth at the upper site may be understood as a lengthening of summer-autumn

dry conditions and reflects growth reduction of LW formation in response to lasting water stress. This means that water availability in the period when the maximum LW growth occur is a critical factor affecting radial growth with cascading effects on water conduction and carbon uptake. Moreover, this result suggests that *A. borisi-regis* LW relies primarily on precipitation amounts at the early summer and to a lesser extent, on ground water, which agrees with dendroecological studies of other Abies species (Linares et al., 2009). The lack of a relationship between spring precipitation, temperatures and radial growth has also been observed in other conifers (Lebourgeois et al., 2010) and can be explained by spring radial growth being partly supported by previous-year photosynthesis and moisture reserves supplied by the snow melting during the early part of the growing season. Climate conditions during the previous year generally determine the amount of reserves, which are used in further growth resumption (Helle and Schlesser, 2004; von Felten et al., 2007). The positive (negative) correlation between the growth components and summer precipitation (temperatures) suggest that *A. borisii-regis* growth may be very susceptible to water availability during this part of the growing season. The high sensitivity to summer temperatures indicates that warm summers are unfavorable for growth at all sites since growth decline in *A. borisii-regis* were observed in response to warming-induced drought stress. High temperatures increase evapotranspiration and water deficit which affects photosynthetic activity, the formation of metabolic reserves and consequently radial growth (Hsiao, 1973; Linares and Tíscar, 2010). These growth reductions during summer months may indicate a low adaptation capacity derived from a low drought avoidance threshold as observed in other fir species (Linares et al., 2009). On the other hand, the positive association of LW growth with previous October precipitation and December temperature indicates that *A. borisii-regis* growth is depended by previous year climatic conditions which could enhance the LW growth through a direct improvement of EW growth as found by the relatively high relationship between them. Warm temperatures and wet conditions in winter can favor an earlier onset of growth in spring, longer growing season, higher photosynthesis and carbohydrate allocation to the stem as observed in other fir species (Guehl and Aussenac, 1987; McDowell and Sevanto, 2010; Rolland et al., 1999). An improved production of EW tracheids with wide lumens may result in an increase of hydraulic conductivity and photosynthesis leading to the synthesis of more carbohydrates for LW formation in summer and early autumn (Linares, 2011). The high sensitivity of EW, LW TRW growth to cumulative drought stress in summer, indicates that accumulated (1-4 months) drought stress during this period are crucial for the radial growth in *A. borisii-regis* which is in agreement with short term rainfall dependence of Mediterranean conifers (Ferrio and Voltas, 2005; Nicault et al., 2001). This association may be explained by the low water-use efficiency of *A. borisii-regis* which is a species whose photosynthetic activity appears to be very sensitive to atmospheric drought and its growth rates respond to warming induced short-term cumulative water deficit in late summer. In mountain conifer forests, the high temperatures in combination with strong radiation can intensify evaporation rates that additionally decrease moisture content in the upper layers of the soil influencing so the soil water balance negatively (Pichler and Oberhuber, 2007; Vicente-Serrano et al., 2010a). Therefore, if drought severity increases in the future as related to enhanced water deficit due to decreased precipitation and high temperatures, severe growth decline and mortality episodes will threaten *A. borisii-regis* populations as has been observed in other mountain conifer species (Camarero et al., 2010; Gruber et al., 2010; Martınez-Vilalta and Piñol, 2002; Sánchez-Salguero et al., 2010). This events will be particularly noticed in mid elevation populations which showed a lower adaptive capacity and a more intense and prolonged impact of drought on growth as compared to the lower and upper sites. Given drought sensitivity and temperature-induced stress of *A. borisii-regis* populations in the study area, the role of drought in growth and distribution of this Mediterranean mountain species will likely become even more important in a global-warming scenario (Parmesan, 2006). If, as climate change models predict, the frequency of drought events in the Mediterranean basin increases as a result of rising temperatures and decreasing spring precipitation (Sumner et al., 2001), we may witness significant changes in growth and distribution of *A. borisii-regis* forests, since summer precipitation and high temperatures were found to be critical for its growth.

Acknowledgements

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