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RADIAL GROWTH RESPONSES OF *PINUS HALEPENSIS* MILL. AND *PINUS PINEA* L. FORESTS TO CLIMATE VARIABILITY IN WESTERN ALBANIA

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Abstract: In this study are presented chronologies of earlywood (EW), latewood (LW) and tree-ring widths (RW) of a *Pinus halepensis* (*P. halepensis*) and *Pinus pinea* (*P. pinea*) natural forest stand growing in western Albania. Bootstrapped correlations and pointer year analysis were combined in a dendroclimatological study to evaluate climate-growth relationships in both pine species as well as to assess the spatial outreach of our chronologies evaluating them with those of the same species from other Mediterranean countries. We found that both species responded positively to precipitation and Indexed Percentage Average Precipitation (%AvP) in late summer-early autumn, particularly the LW, whereas summer temperatures constrained the growth of *P. halepensis* tree-ring features. Current January temperature and Potential Evapotranspiration (PET) showed positive relationship with *P. pinea* LW and RW. The same association was observed when considering PET in spring and *P. halepensis* LW and RW. Pointer year analysis showed that inhibitory climatic drivers of radial growth for both species were low precipitation from previous winter and current summer, associated with low temperatures during autumn. Our *P. halepensis* chronology showed a wider spatial outreach than that of *P. pinea* when compared to those from other Mediterranean countries. We conclude that current January temperatures and September precipitation are very important for *P. pinea* growth influencing both EW and LW growth whereas *P. halepensis* is mostly affected by the summer-early autumn climate conditions.

Keywords: *Pinus halepensis*, *Pinus pinea*, radial growth, climate, bootstrapped correlations, pointer years.

1. INTRODUCTION

Dendrochronological research has a long history in the Mediterranean basin (Akkemik, 2000; Martinelli, 2004; Rathgeber *et al.*, 2005; de Luis *et al.*, 2009). In contrast, the western Balkan is less investigated by dendrochronologists and consequently, there are few studies related to chronology development and climate-growth relationships in some other conifer species. Concerning Albania, for example, Levanič and Toromani (2010) built the first chronology of *P. nigra* Arnold. and studied its response to climate, while Seim *et al.* (2012) constructed a more than 1000 year-long tree-ring width chronology for *P. heldreichii* H. Christ. There are numerous dendrochronological studies about growth dynamics and climate-growth relationship in many Mediterranean species, including *P. halepensis* and *P. pinea* (Andreu *et al.*, 2007; de Luis *et al.*, 2007; Piraino *et al.*, 2013). However, there are no studies related to these species in western Balkan, particularly in Albania, where *P. halepensis* and

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P. pinea grow naturally only at Divjaka and Pishe-Poro sites.

The IPCC's scenarios show a decrease in annual mean precipitation between 10% up to 40% and air temperatures rising by 2°C up to 4°C in the Mediterranean basin over the late twenty-first century which may lead to an increase of evapotranspiration (IPCC, 2007). These climatic episodes are expected to cause more frequent and intense droughts in the region, leading to tree growth decline and mortality events as those observed by some authors (Macias *et al*., 2006; Linares *et al*., 2009; Galiano *et al*., 2010). The Mediterranean pine species have been used to study the relationship between climatic trends and their growth in several studies (Campelo *et al*., 2006; Martín-Benito *et al*., 2007; Bogino and Bravo, 2009; Vieira *et al*., 2009). For example, Akkemik (2000) found that spring-summer precipitation and temperatures at the beginning of the growing period have a significantly positive influence on *P. pinea* radial growth. Rathgeber *et al.* (2005) indicated that *P. halepensis* growth is mainly controlled by soil water availability during the growing season. As summer drought is becoming increasingly important for pine forest growth at low elevation sites in the Mediterranean basin (de Luis *et al*., 2009; Olivar *et al*., 2012; Piraino *et al*., 2013), it is vital to understand how pine's populations growing in Western Albania responded to summer drought in the past.

In Albania, conifer forests cover an area of 104780 ha with a standing volume of 10.7 million cubic meters, while the Mediterranean pine species occupy 18440 ha. *P. halepensis* and *P. pinea* cover approximately 85% of that area (ANFI, 2004). These species are distributed at an elevation up to 400 m a.s.l. and have been widely used in the past for reforestation to control the erosion or establish wind protection belts.

This study aims to analyse how the climate variability during the second half of the 20th century affected the patterns of radial growth of *P. halepensis* and *P. pinea* stands growing at natural site in Divjaka National Park, Western Albania. The objectives were to: (*i*) construct EW, LW and RW chronologies for *P. halepensis* and *P. pinea*; (*ii*) investigate the relationships between climate and radial growth of both species; (*iii*) compare the newly developed chronologies for both pine species with other *P. halepensis* and *P. pinea* chronologies from the Mediterranean basin and neighbouring countries.

The hypothesis of this study was that local climate conditions will affect differently both pine species considering their physiological and growth adaptation in response to climatic stress (Borghetti *et al*., 1998; Oliveras *et al*., 2003; Campelo *et al*., 2006) and such impact is expected to be higher on EW than LW growth since EW formation is strongly influenced by moisture conditions during summer months (Pasho *et al*., 2012).

2. MATERIALS AND METHODS

Study area

The study area is situated on the Western coast of Central Albania, within the National Park of Divjaka-Karavasta (41º00' N, 19º29' E, elevation 3 m a.s.l.) (**Fig. 1**). The area is characterized by a high biological and ecological diversity. It represents a mixed natural pine ecosystem composed of *Pinus halepensis* and *Pinus pinea* with a rich understory vegetation composed of shrubs and grasses. The soil type is alluvial meadow which is formed on alluvial deposits with medium texture and high water holding capacity (Zdruli, 1997). The pine species stands grow under Mediterranean climate conditions, characterized by mild (wet) winters and hot (dry) summers. The mean annual temperature for the period 1950–2009 was 15.4°C, ranging from 5.9°C (January) to 24.9°C (July). Winter temperature (average of 7°C) ranged from 3.5°C to 10.2°C whereas summer temperature (average of 24.1°C) ranged from 20.2°C to 27.8°C. Precipitation shows a high variability among seasons, characterized by the highest amount in winter (333.4 mm) and the lowest in summer (107.1 mm). Water deficit in the study area lasts 5 months (May–September) being the most severe on July and August (**Fig. 1**).

Data collection and chronology development

Tree-ring chronologies were developed from wood samples using standard dendrochronological procedures (Stokes and Smiley, 1968). Twenty *P. halepensis* and fifteen *P. pinea* dominant healthy trees were randomly selected and two radial cores per tree were extracted at 1.3m above the ground using a Pressler increment borer. Cores were mounted on a wooden board and sanded with progressively finer grades of sandpaper to produce a flat, polished surface on which tree-ring boundaries were clearly visible under stereoscope magnification. Due to the clear distinction between the EW-LW transitions we measured their width and that of RW with an accuracy of 0.001 mm using a LINTAB measuring system (Rinntech Hiedelberg, Germany) and the program TSAP-Win. The visually cross-dating was evaluated using COFECHA software (Holmes, 1983). Each ring-width series was detrended and standardized to remove age-related growth trends (Fritts, 1976; Cook and Kairiukstis, 1990). The standardisation was performed with the software ARSTAN (Cook and Holmes, 1984). The series of raw data were processed with a double detrending. First, a negative linear or exponential function was fitted. Then, we used cubic smoothing splines with a 50% frequency response cut off of 30 years to keep the high-to-medium frequency response to climatic variability (Cook and Peters, 1981). The residual series were then averaged using a bi-weight robust mean function to construct the site residual chronologies of EW, LW and RW.

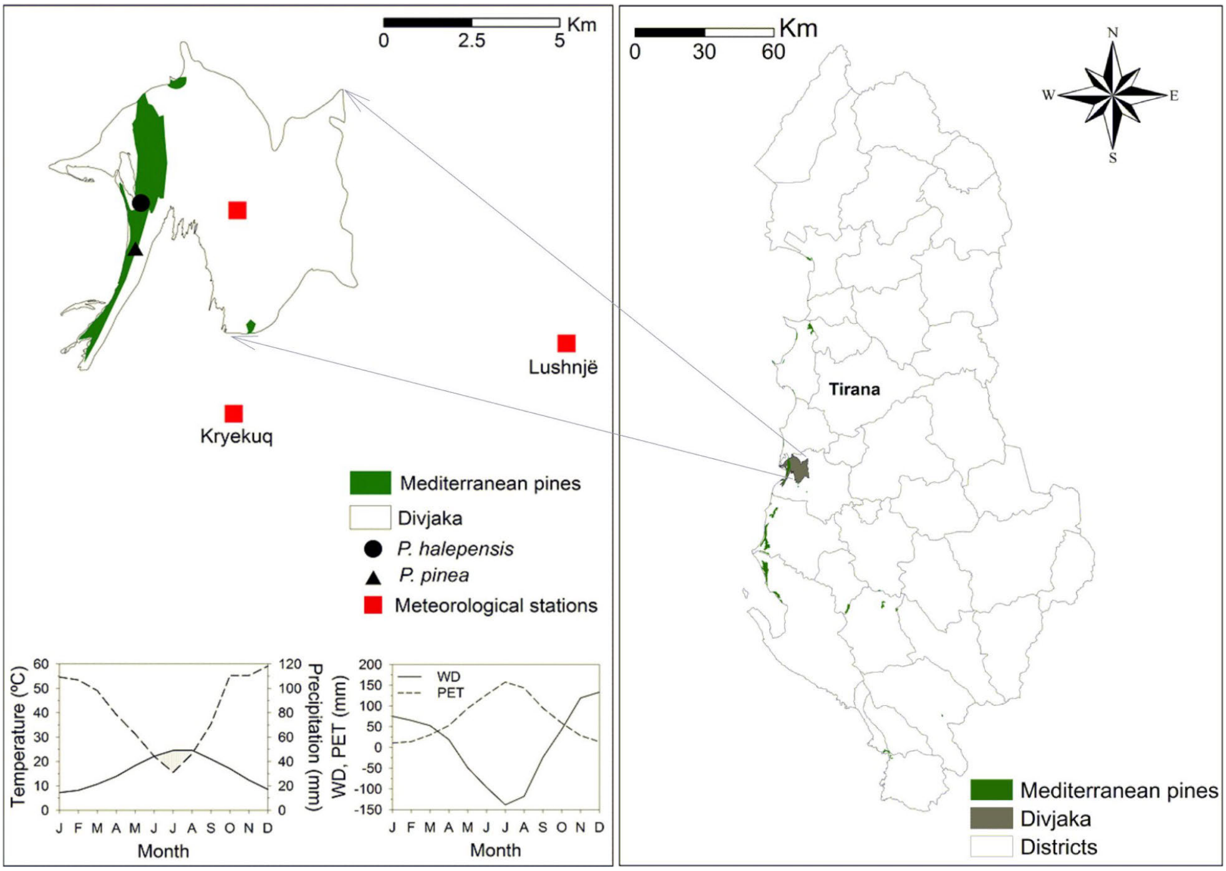

Fig. 1. *Map of Albania including the Divjaka region (right side), climate diagrams (lower part — left side), the sampled locations and the meteorological stations (left side).*

The basic statistics evaluated for each chronology were: mean tree-ring width (MW), mean sensitivity (MS) that is a measure of the relative change in ring widths between successive years, standard deviation (SD), first order autocorrelation (AC1) which reflects the influence of the previous year's growth on current growth and expressed population signal (EPS) which indicates to what extend the sample size is representative of a theoretical infinite population. The common period 1960–2009 was used for dendroclimatic analysis, because EW, LW and RW residual chronologies of both pine species showed EPS values greater than 0.85 threshold which is widely used in dendrochronological studies (Wigley *et al.*, 1984).

Additionally, 10 RW chronologies (3 for *P. halepensis* and 7 for *P. pinea*) developed from various sites in Mediterranean basin were downloaded from ITRDB webpage (The International Tree-Ring Data Bank: www.ncdc.noaa.gov/paleo/treering.html). They consisted of *P. pinea* chronologies from Circeo (Italy, elevation 0 m a.s.l., 1885–1988 — Biondi, 1995a), San Rossore (Italy, elevation 0 m a.s.l., 1897–1988 — Biondi, 1995b), Dehesa del Peral (Spain, elevation 1055 m a.s.l., 1874–2001 — Briongos and Cerro-Barja, 2005a), La Pasadilla (Spain, elevation 705 m a.s.l, 1908–2001 — Briongos and Cerro-Barja, 2005b), Cuenca (Spain, elevation 700 m a.s.l., 1916–1999 — Briongos and Cerro-Barja, 2005c), San Clemente (Spain, elevation 720 m a.s.l., 1882–1999 — Briongos and Cerro-Barja, 2005d), Addeldal (Morocco, elevation 900 m a.s.l., 1843–2004 — Touchan *et al.*, 2010b) and *P. halepensis* chronologies from Marseille (France, elevation 200 m a.s.l., 1807–1974 — Serre-Bachet, 1995), Dahllia (Tunisia, elevation 950 m a.s.l., 1893–2003 — Touchan *et al.,* 2010c) and Jebnoun (Tunisia, elevation 800 m a.s.l., 1877–2003 — Touchan *et al.,* 2010d).

The RW series from these sites were compared to our RW chronologies by calculating the Gleichlaufigkeit values (GLK), Baillie-Pilscher test values (t-BP) and Pearson correlation's coefficient (R), in order to evaluate the spatial outreach of Albanian chronologies.

Dendroclimatic analyses

The radial growth-climate relationship was assessed by means of bootstrapped correlation function (BCF). The climate data consisted of monthly mean temperature (T), monthly total precipitation (P), Potential evapotranspiration (PET) and Indexed Percentage Average Precipitation (%AvP). The T and P data were provided from two sources: a local meteorological station (Divjaka, 40°58’49”N, 19°29’28”E elevation 4 m a.s.l.; period 1950–2009) and the database of KNMI Climate Explorer web page (http://climexp.knmi.nl/) where we obtained gridded CRU TS 3.1 data (period 1950–2009) with a resolution 0.5° × 0.5° (41–41.5°N, 19–19.5°E) (Mitchell and Jones, 2005). The involvement of two additional local weather stations (Kryekuq and Lushnjë) apart from that of Divjaka was done with the purpose of filling gaps in the climate data of Divjaka station whereas the CRU data was used to calibrate the local climate data. PET was calculated using Thornthwaite equation (Thornthwaite, 1948) whereas the %AvP was computed by dividing actual monthly precipitation with long term average precipitation calculated over 1960–2009 base period and multiplied by 100 (Hayes, 2007).

The bootstrapped correlations were computed between the EW, LW and RW residual chronologies of both pine species and the climate data of P, T, PET and %AvP over the common period 1960–2009 using a 15-month window from October of the year prior to tree-ring formation (year $t - 1$) until December of the year of growth (year t). For this analysis we used the program DENDROCLIM 2002 and the bootstrap method (Guiot, 1991; Biondi and Waikul, 2004).

In addition, the common climate signal in tree-ring widths of both pine species was investigated using pointer’s year analysis (PYs) according to Cropper’s method (Cropper, 1979). The critical level used for identification of narrow or wide rings was set 0.75 (it ranged from 0.5 to 1.0 according to Cropper (1979)). Each ring width was compared to running mean (means for 5 years interval) in order to determine the relative narrowness or largeness. The presence of a relatively narrow (large) ring was identified if it was narrower (larger) than the mean ring width calculated for the specified number of rings per interval minus (plus) standard deviation multiplied by the critical level (0.75). According to Schweingruber *et al.* (1990), PY’s are defined as years where at least 80% of 13 trees respond with an increase or decrease in tree-ring width. Positive and negative PYs were compared with anomalies of seasonal climatic variables to identify the appropriate climatic variables which affect the species radial growth in those particular years. For each season were calculated the anomalies of temperatures (T) and precipitation (P) from long-term average (considered as reference value) for the period 1960–2009. Thus, a positive value of anomaly indicated that the observed T/P was higher than the reference value and the vice versa.

3. RESULTS

Characteristics of tree-ring chronologies

The site chronologies were built using 20 *P. halepensis* and 15 *P. pinea* sample trees (**Fig. 2**, **Table 1**). The pine species populations were of different age, ranging from 47–62 years for *P. halepensis* to 39–163 years for *P. pinea*. Statistical parameters (MS and AC1) indicated differences between the residual chronologies of both species, particularly the LW which showed the highest values of MS and lowest of AC1. The EW accounted for 65% and 68% of the total ring width of *P. halepensis* and *P. pinea,* respectively.

The spatial outreach of Albanian pine’s chronologies

Our *P. halepensis* chronology was significantly correlated with that of Jebnoun from Tunisia (**Table 2**), ($R = 0.53$, $p < 0.05$, common period 1949–2003; GLK = 67%; t-BP = 5.56). *P. pinea* chronology showed high and significant correlation only with San Rossore chronology from Italy ($R = 0.81$, $p < 0.05$, common period 1861–1988; GLK = 75%; t-BP = 24.80).

Radial growth-climate relation

The BCF indicated that radial growth of both pine species responded positively to P and %AvP in summer-early autumn, particularly the LW, whereas summer T affected negatively the growth of *P. halepensis* EW, LW and RW (**Fig. 3**). Winter T and PET showed positive association with *P. pinea* LW and RW. The same relationship was observed when considering LW and RW of *P. halepensis*, and PET in April.

Table 1. *Basic statistics of Pinus halepensis and Pinus pinea EW, LW and RW residual chronologies.*

Variables	Species	Time span	Mean tree age ± SD	Min-max age (year)	MW (mm)	MS	SD (mm)	AC1	EPS > 0.85
RW	*P. halepensis*	1949–2010	52 ± 5	33–62	3.83	0.24	1.32	0.73	1960
	P. pinea	1848–2010	103 ± 42	36–161	2.82	0.23	1.90	0.78	1895
EW	*P. halepensis*	1949–2010	52 ± 7	33–62	2.40	0.26	0.94	0.71	1960
	P. pinea	1848–2010	103 ± 42	36–161	1.50	0.23	0.99	0.76	1895
LW	*P. halepensis*	1949–2010	53 ± 3	33–62	1.30	0.37	0.46	0.68	1960
	P. pinea	1848–2010	103 ± 42	36–161	0.76	0.34	0.65	0.65	1895

Statistics of the chronology time span: Raw-data series: MW — mean ring width; AC1 — first-order autocorrelation; SD — standard deviation. Residual series: MS — mean sensitivity; EPS — expressed population signal (the first year when EPS is greater than 0.85).

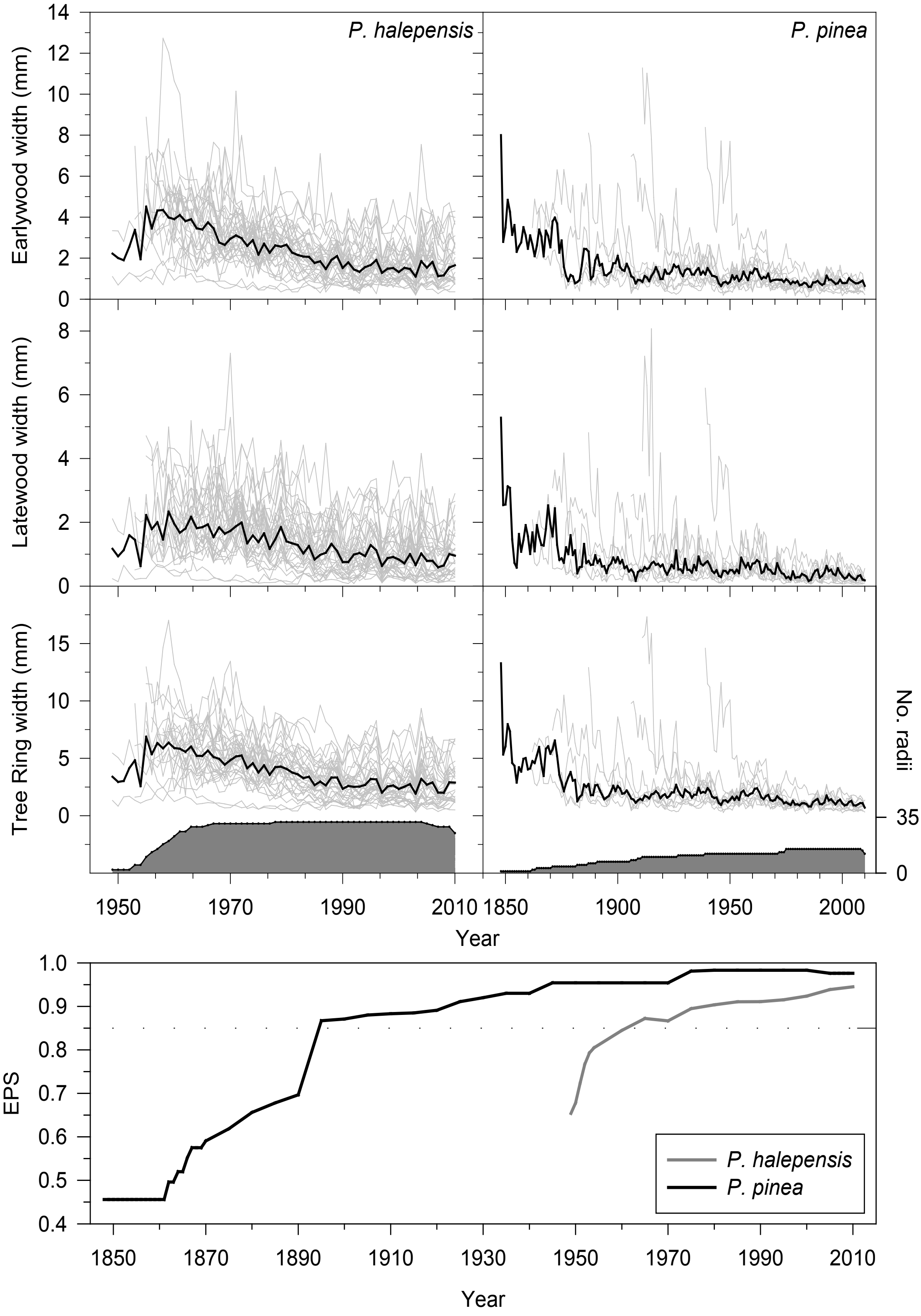

Fig. 2. *Raw tree-ring chronologies (EW, LW and RW) (upper graph), and expressed population signal (EPS) (lower graph) of RW residual chronologies of P. halepensis and P. pinea. The dashed line in the lower graph displays the critical threshold of EPS (0.85).*

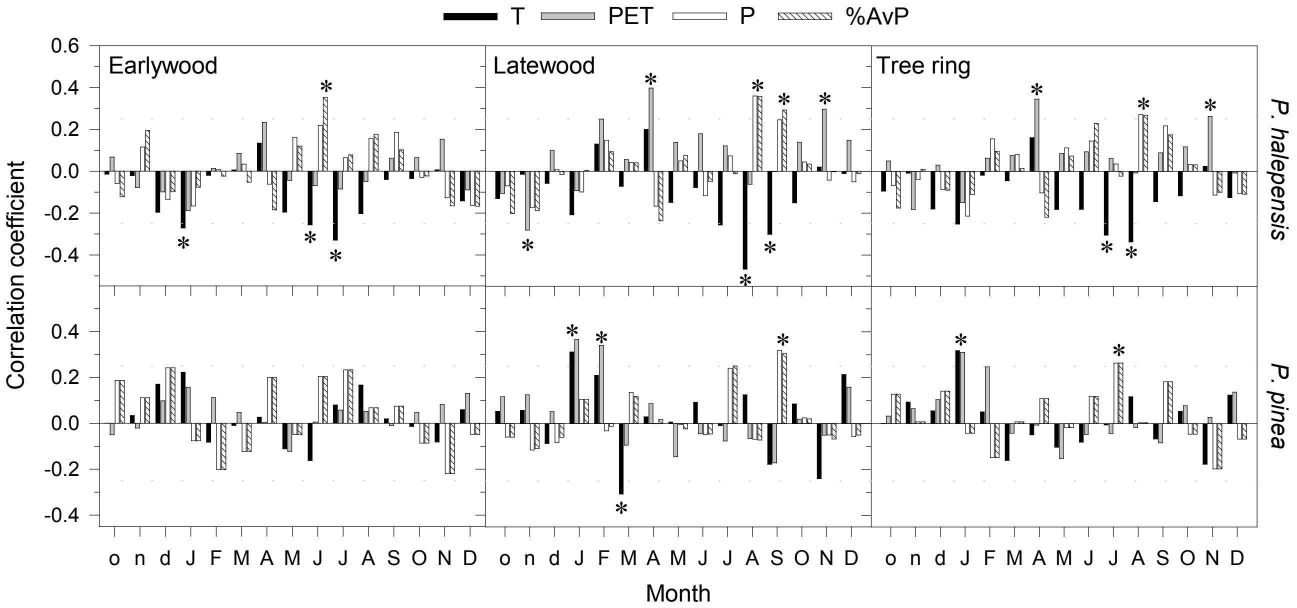

Fig. 3. *Bootstrapped correlation coefficients for climate-growth relationships of P. halepensis and P. pinea. Correlations were calculated considering climatic data of the year of tree-ring formation (t, months abbreviated by capital letters) and the preceding year (t - 1, months abbreviated by minor letters) over the period 1960–2009. Statistically significant values (p ≤ 0.05) are marked with stars. T — monthly mean temperature, P — monthly total precipitation, PET — Potential evapotranspiration and %AvP — Indexed Percentage Average Precipitation.*

Table 2. *The relationships between P. halepensis and P. pinea RW chronologies of our site with those from other Mediterranean countries.*

Species	Chronologies	Overlapping period	*R*	GLK %	t-BP
P. halepensis	Jebnoun, Tunisia	1877–2003	0.53*	67*	5.56*
	Marseille, France	1807–1974	–0.31	63	2.24
	Dahllia, Tunisia	1893–2003	–0.02	57	0.12
P. pinea	San Rossore, Italy	1897–1988	0.81*	75*	24.8*
	Circeo, Italy	1885–1988	0.50*	64	6.96*
	Dehesa del Peral, Spain	1874–2001	0.42	56	5.35*
	La Pasadilla, Spain	1908–2001	0.32	54	2.45
	Cuenca,Spain	1916–1999	0.39	55	3.81
	San Clemente, Spain	1882–1999	–0.38	47	4.43
	Addeldal, Morocco	1843–2004	0.80*	48	16.6*

* *Relationships between pine species chronologies were considered significant only for values higher than thresholds of all statistical parameters [R (p < 0.05), GLK > 65% and t-BP > 4.00] together.*

PYs coincided partly in-between all *P. halepensis* and *P. pinea* chronologies (**Table 3**). The applied procedure resulted in total amount of 11 and 7 pointer years in the period 1960–2009 for *P. halepensis* and *P. pinea*, respectively. Only two of them were common positive (1963, 1988) and negative (1985, 2005) pointer years. The analysis of pointer years revealed five positive (1963, 1988, 2000, 2004, 2006) and six negative pointer years (1975, 1985, 1990, 2001, 2003, 2005) for *P. halepensis* as well as five positive (1963, 1972, 1988, 1990, 1993) and two negative pointer years (1985, 2005) for *P. pinea*.

The climatic drivers constraining the growth of both species in particular years (*i.e.* 1985) were low P from previous winter to current summer associated with low T during autumn or low P from spring to summer accompanied with low autumn T (*i.e.* 2005) (**Table 3**). The years in which both species produced wide rings were common and characterised by high winter - current summer P associated with warmer autumn T (*i.e.* 1963) or low T during summer and abundant P during winter and current summer (*i.e.* 1988).

4. DISCUSSION

In this study we present the relationship between climate and tree-ring chronologies of *P. halepensis* and *P. pinea* from Western Albania. The MS of the residual chronologies showed a higher variability of *P. halepensis* LW due to local climatic fluctuations than EW and RW (Rolland, 1993). The LW is formed during late summer and autumn, and is mostly affected by the temperatures and precipitation amounts during that period (de Luis *et al.*, 2007; Camarero *et al.*, 2010).

The spatial variation of the correlations between our chronologies and those from other regions could be due to differences in climatic and growing conditions in these sites or other factors. Thus, the evident discrepancy between our chronologies with others from Dahllia (Tunisia) and Spain is result of the broad altitudinal difference

Table 3. *Common and uncommon pointer years of P. halepensis and P. pinea RW chronologies and potential climatic drivers for the period 1960–2009.*

Pointer years	Indices in chronology		WIN		SPR		SUM		AUT	
	P. halepensis	*P. pinea*	T	P	T	P	T	P	T	P
1963	high	high	0.5	157.8	1.5	–9.3	3.9	61.4	1.5	–70.8
1972		high	–1.0	–23.2	0.7	–52.3	2.1	32.2	1.6	–0.4
1975	low		0.7	–183.9	0.3	–39.6	1.9	–9.8	1.5	–44.5
1985	low	low	0.5	–84.8	1.3	–14.5	1.3	–34.2	0.1	80
1988	high	high	0.3	16.1	–1.3	–6.7	0.9	21.2	1.0	–110.9
1990	low	high	–1.8	–210.3	–0.1	–50.5	2.3	–35.1	1.0	32.1
1993		high	0.1	–131.8	1.0	71	1.4	–43.8	0.3	104.1
2000	high		–0.6	16.1	0.6	100.3	1.1	–10.8	0.9	147.3
2001	low		0.2	34.7	0.6	28.7	2.0	–45.4	0.4	–118
2003	low		0.1	103.9	0.8	–126.4	0.9	–22.3	–0.6	109.5
2004	high		–0.3	8.5	–0.1	47.7	0.8	–1.1	1.3	–49.2
2005	low	low	1.0	74.9	1.3	–27.6	1.6	–9.8	–1.3	31.2
2006	high		0.6	3.2	–0.3	29.8	0.8	46.4	1.1	–93.7

Pointer years identified in ring width chronologies of pines species are compared to seasonal climatic variables (WIN-prior December to February; SPR-March to May; SUM-June to August; AUT-September to November). Numbers represent temperatures (T) and precipitation (P) anomalies from long-term average (considered as reference value).

among these sites ranged from 700 to 1055 m a.s.l., implying that temperature is the main factor which control the radial growth of pines in those sites (Touchan *et al*., 2010).

Although our *P.pinea* chronology was fitted well with chronologies from Italy, they had differences in some basic statistics of residual chronologies. This difference might be because the Italian chronologies were built by a limited number of specimens (7 (San Rossore) and 9 (Circeo) sampled trees) having a lower mean sensitivity (0.13) and signal-to-noise ratio (1.4–5.4) (Biondi, 1992) than our *P.pinea* chronology.

In general, growth of coexisting species showed different responses to monthly climatic oscillations. In *P. halepensis*, negative correlations to summer, early autumn temperature combined with positive association to August precipitation suggest an overall tendency to drought sensitivity. These findings point out that high summer temperatures are unfavourable for growth of this species and this could be worsening if predicted increase of temperature will happen as consequence of climatic change. The lowest radial growth in this species coincides with the years (2001, 2003, *etc.*) in which were recorded the most severe heat events in the Mediterranean basin (Sánchez *et al*., 2004). These results are similar to those found in other regions for the same species growing under similar site conditions (de Luis *et al*., 2009; Vieira *et al*., 2009; Olivar *et al*., 2012). High temperatures increase evapotranspiration and water deficit which reduces photosynthetic activity and tracheid division rates, reducing the radial growth (Hsiao, 1973; Linares and Tiscar, 2010; Vicente-Serrano *et al*., 2010). However, wet conditions in August enable it to keep active LW growth.

On the other hand, *P. pinea* growth showed a low dependence to climatic conditions during the growing season. This result suggests that growth in this species is less limited by warming induced drought stress during summer as compared to *P. halepensis*. This ability might be related to physiological-age interactions as *P. pinea* is characterised by high capacity to store water which minimizes water stress during summer, it reduces photosynthesis when water stress occurs and its high hydraulic conductivity enables the efficient use of underground waters (Liphschitz *et al*., 1984; Oliveras *et al*., 2003; Teobaldelli *et al*., 2004; Campelo *et al*., 2006). *P. pinea* trees in the study area are older than those of *P. halepensis* and such trees are less sensitive to drought conditions as opposed to the young trees (Carrer and Urbinati, 2004; de Luis *et al*., 2009; Olivar *et al*., 2012). However, we found significant positive relationship of RW and LW in *P. pinea* to July and September precipitation, showing a dependency to precipitation regime during this period. Certainly, improvement of moisture balance during autumn season is beneficial for LW formation as reported by Akkemik (2000). We also noted that both pine species had a different response to January temperatures. The negative response of *P. halepensis* EW chronology to January temperatures implies that unfavourable winter temperatures may trigger a delay in the start of EW formation. However, *P. pinea* LW showed positive correlation with January temperatures and January–February PET. This relationship could be explained by the fact that warm conditions in winter can favour a direct improvement of EW formation (Campelo *et al*., 2006; Piraino *et al*., 2013) leading to an indirect LW enhanced growth. This indicates that the LW growth is not only determined by the climatic conditions during summer – autumn, but also by the previous EW growth rates (Pasho *et al*., 2012). The LW formation of *P. halepensis* responded positively to P, %AvP during current autumn, suggesting that autumn precipitation may be important for LW growth in *P. halepensis*. This is consistent with phenological observations that cambial activity in *P. halepensis* can be greatly enhanced after summer because of autumn rainfall (de Luis *et al*., 2007; Camarero *et al*., 2010).

Lastly, it should be stated that in our study site, both species grow on a narrow strip of alluvial sandy soils and the underground water table is affected by salty waters. The influence of salt on roots and on the absorption of the phreatic waters is detrimental to the growth of both pine species and particularly of *P. pinea* during periods of low precipitation (Teobaldelli *et al*., 2004; Piraino *et al*., 2013). Consequently, the presence of salty waters might bias the relation of tree growth with climatic parameters as found elsewhere (Piraino *et al*., 2013).

Based on the study findings we conclude that *P. pinea* shows differences in growth and response to local climatic conditions compared to *P. halepensis*. These findings complement the existing dendroclimatological information on *Pinus* spp growth from this part of the Mediterranean basin.

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