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Spatial and temporal variation in Bosnian pine (Pinus heldreichii Christ.) growth due to climate in Kosovo

Faruk Bojaxhi [1*], Elvin Toromani [2]

[1] *Kosovo Forest Agency, Zenel Saliu street 1/a, 10000 Pristina, Kosovo*
[2] *Agricultural University of Tirana, Faculty of Forestry Sciences, Koder Kamez, AL-1029 Tirana, Albania*

Abstract

The purpose of this study was the identification of the dominant temporal and spatial patterns of *P.heldreichii* growth due to climate from three high elevation sites in Kosovo. Bootstrap correlation analysis, forward evolutionary analysis were used to study the temporal and spatial patterns of climate-growth relationship. *P.heldreichii* chronologies have a length from 175 to 541 years and a greater similarity along the latitudinal gradient. Growth - climate relationship pointed out that *P.heldreichii* growth vary due to the combined effect of summer precipitation with winter temperature providing a better understanding of this response at spatial and temporal scales. Future research focused on the analysis and integration of *P.heldreichii* growth along latitudinal and longitudinal gradients, as well as on the spatial and temporal patterns of temperature and precipitation records will improve the knowledge of long-term climate fluctuations during the last century in Kosovo.

Keywords: Kosovo, *P.heldreichii*, High Elevation, Spatial Variation, Temporal Variation

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[*] Corresponding author. *E-mail address:* farukbojaxhi@yahoo.com

1. Introduction

Tree-ring from trees grown on high elevation sites, are highly sensitive to climate variations and thus provide clear evidence of changes in tree's growth. These sites are less disturbed by logging and human set fires and may provide long records to monitor environmental changes at a variety of time-scales (Luckman, 1990; Villalba et al., 1997). *Pinus heldreichii* Christ. is one of the main conifer species that dominates tree line in the Kosovo mountainous. It covers an area of 2150 ha and usually form pure and mixed forest stands with silver fir (*Abies alba* Mill.). The natural forest stands of this species in Kosovo are situated in Prevalla, Koritnik and Decani mountainous regions. Studies using *P.heldreichii* tree rings for climate-growth relationship exploring have been carried out in several countries. Thus, previous studies have been conducted in Bulgaria (Panayotov et.al., 2009; Panayotov et.al., 2010), Greece (Branders, 2007; Griggs et.al., 2007), Albania (Seim et.al., 2012). Available research on *P. heldreichii* growth at high elevation sites from Kosovo are focused only on the analysis of climate-growth relationship but no evidence is provided on temporal patterns and spatial strength of this species growth. Previous dendroclimatic studies conducted in Kosovo, found that Bosnian pine growing in high elevation locations is sensitive to summer drought stress and the magnitude of sensitivity was higher in young trees (Bojaxhi and Toromani 2016). Therefore, a comprehensive analysis of temporal patterns and spatial strength of *P.heldreichii* radial growth at high elevation through its entire geographic range is needed. The aim of this paper was: (i) to identify the dominant temporal patterns and spatial strength of *P.heldreichii* radial growth at high elevation sites in Kosovo; (ii) to study the growth-climate relationship in the research area.

2. Material and methods

2.1. Study area

We sampled 98 *P.heldreichii* trees at three high elevation sites at Prevalla (hereafter, PRE), Strelc-Decan (hereafter DE) and Koritnik (hereafter, KO), covering the entire geographic distribution of this species in Kosovo (Table 1). The elevation between the sampled sites range from 1815 to 1945 m above sea level (a.s.l).

Table 1. Geographical characteristics of the sampled sites

Location	Code	Lat ° N	Long ° E	Altitude (m a.s.l.)	Slope aspect
Prevalle	PRE	42°11'01.3"	20°57'42.0"	1945	South-West (SW)
Decan	DE	42°36'19.8"	20°14'52.5"	1830	South-West (SW)
Koritnik	KO	42°04'46.5"	20°31'58.6"	1815	North-East (NE)

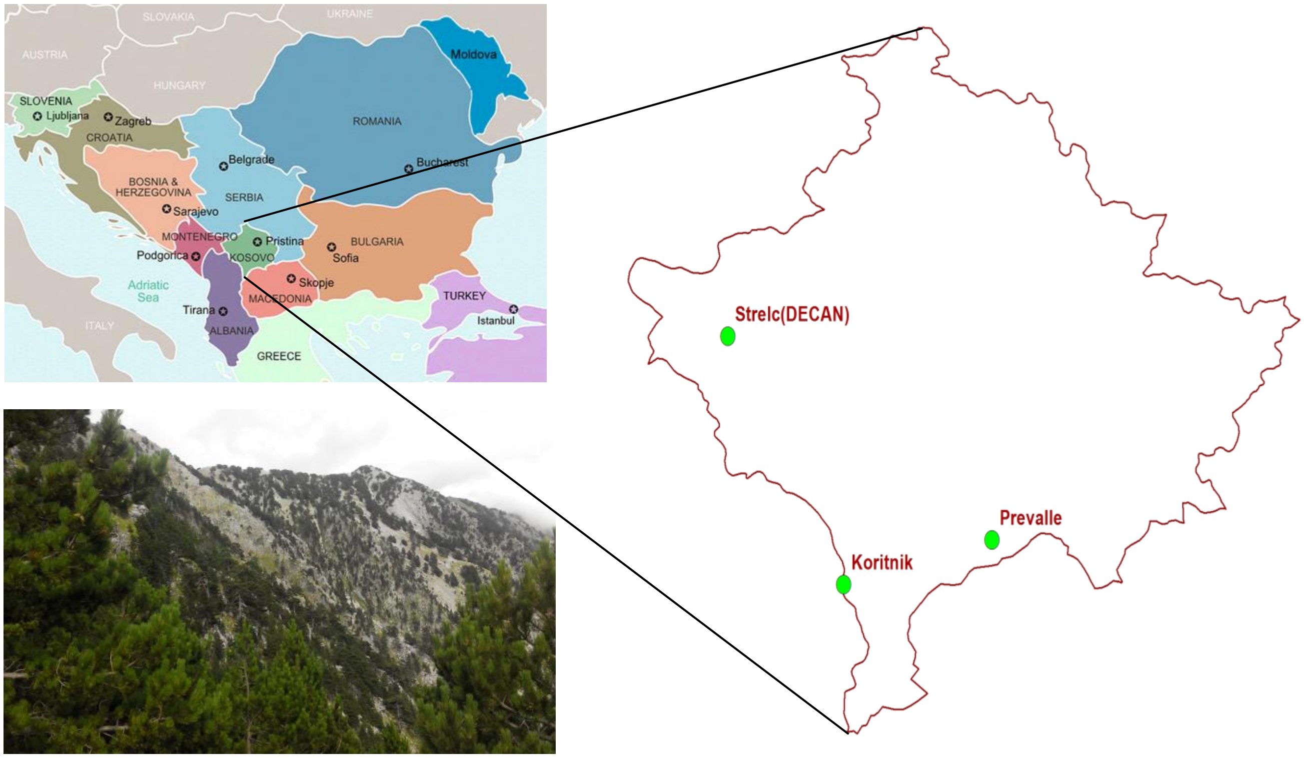


Figure 1. Locations of sampling sites in Kosovo (right side) and images of *P.heldreichii* stands (below)

Typical soils occurred in all sampled sites are carbonate brown soils formed by the long-term alteration of limestone bedrocks. *P. heldreichii* is growing under the influence of Continental climate mixed with Mediterranean in southern Kosovo. Annual mean temperature range from 8.0 °C (PRE-site) to 8.3 °C (KO-site) while precipitation patterns indicate an irregular distribution throughout the year reaching the maximum values on May and November. Monthly sum precipitation is quite equitably distributed over the winter, spring and autumn seasons and with a significant variability among sites during the summer (Figure 2).

2.2. Field and laboratory methods

Two opposite cores from 30 to 38 healthy living trees were collected using increment borers. Cores were mounted, sanded and cross-dated following standard dendrochronological procedures (Stokes and Smiley 1968). Ring widths were measured to the nearest 0.001 mm with a LINTAB 6 (Rinntech, Heidelberg) system and TSAP-Win software and cross-dated visually and confirmed statistically using the software COFECHA (Holmes, 1983). We used the ARSTAN program (Cook, 1985) to standardize all series applying a double detrending procedure. First detrending was conducted using a negative exponential curve, while second detrending was done using cubic smoothing splines curves of 30 years in order to preserve the common climatic signal. The actual ring measurements was then divided by the predicted value to produce a dimensionless index of growth for each year . The master chronology was created for each site by averaging all indices of tree growth for each year across all series (Cook, 1985). Signal strength of each site chronology was tested using expressed population signal (EPS) (Briffa, 1995). According to Wigley et al., (1984), a threshold value for EPS ≥ 0.85 for each site chronology was considered adequate to reflect a common growth signal.

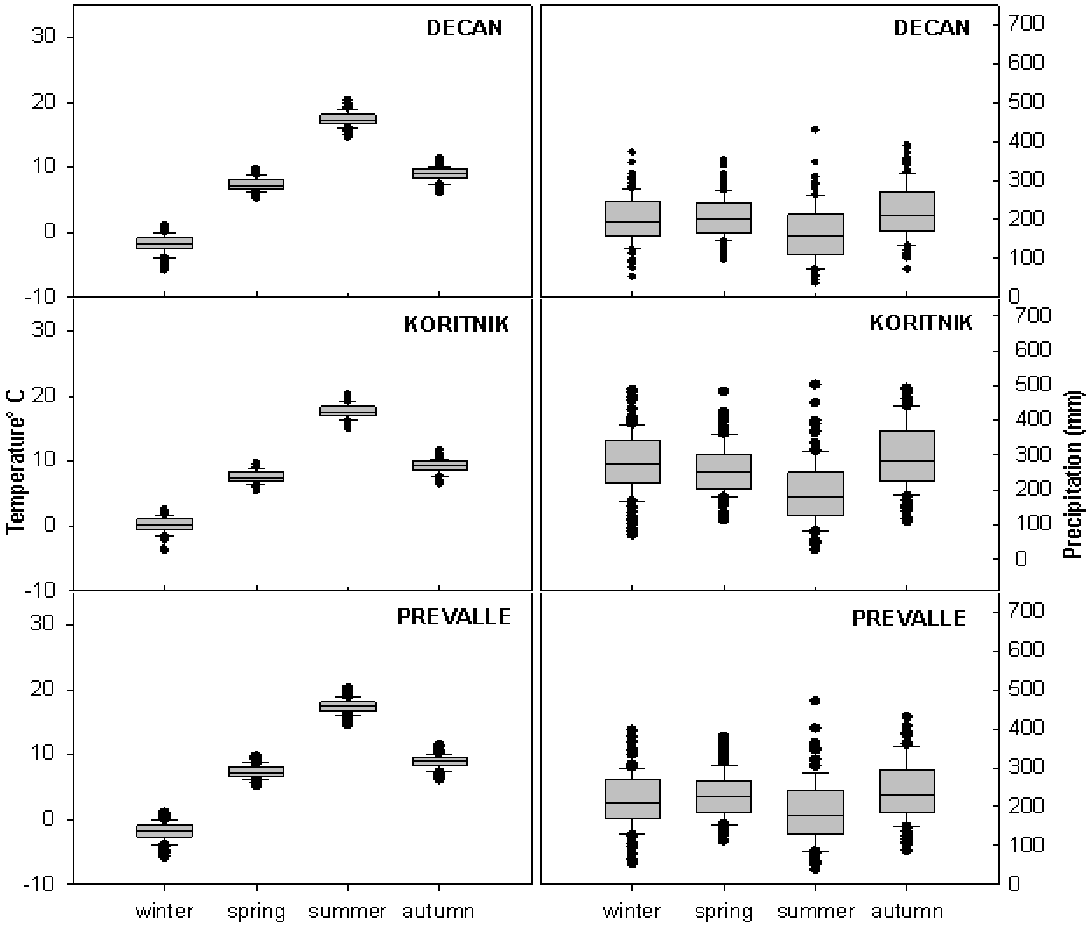


Figure 2. Seasonal distribution of mean temperature and total precipitation for the period 1901-2013 in the research sites. Horizontal lines in the box plots correspond to median values.

2.3. Meteorological data

Due to the sparsity of long local climate series, a 0.5° x 0.5° resolution gridded climate dataset (CRU TS 3.23, Mitchell and Jones 2005) for the period 1901–2013 was used. For each site, monthly mean temperatures, precipitation sums from the closest grid points were extracted from the Climate Explorer (https://climexp.knmi.nl, van Oldenborgh et al., 2009). The gridded climate data for the common period 1951-2013 were considered reliable for the climate - growth spatial and temporal relationship.

2.4. Evaluation of the growth-climate relationship

We used DendroClim 2002 (Biondi and Waikul 2004) to investigate relationships between climate and the residual *P.heldreichii* chronologies at three studied sites (Fritts, 1976). The analysed time window started with May of the preceding year and ended with October of the current growing season to study the effects of climate during the previous year on current year radial growth (Fritts, 1976; Grissino-Mayer 1995). We applied forward evolutionary interval analysis (FEI) to provide a complementary assessment of temporal stability for significant monthly climate- growth relationships. FEI begins with the earliest year in common to all variables, from which forward evolutionary intervals are progressively enlarged by adding one year to a base interval length at each iteration (Biondi and Waikul 2004). To test the spatial strength and outreach among *P.heldreichii* residual tree-ring width chronologies and climate variables we exported them to KNMI Climate Explorer and run the spatial correlations (Van Oldenborgh, 1999).

3. Results

3.1. Tree-ring chronologies

The length of site chronologies vary among sites. Thus, the chronology from DE site was the longest with 541 years, spanning the period 1474-2014 with a replication of more than 35 trees from 1770 onwards. The youngest chronology belongs to KOR site reaching a length of 176 years with a sample replication of 25 trees (Figure 3, Table 2).

The mean ring-width during the common period 1840–2014 ranges from 1.06 mm year^{-1} (DE) to 2.13 mm year^{-1} (PRE). Mean sensitivity, characterizing the year-to-year variability in tree-ring width ranges from 0.212 to 0.245. The southernmost chronology (KOR) has a higher inter - annual variability which accounts for a relatively higher mean sensitivity and standard deviation compared with the northern ones. High values of first-order autocorrelation found at all chronologies indicated that *P.heldreichii* growth is affected by the climatic conditions of the year prior to growth. Chronologies from these sites were well cross-dated and significantly correlated ($p < 0.01$) with each other for the common overlapping period (Table 3.).

Similarity coefficients were higher between Decani and other chronologies, but slightly lower among Prevalla and Koritnik chronologies. The comparison among site chronologies showed that the degree of agreement in radial growth appears to be unrelated to the vicinity between sites. We noted a greater similarity among chronologies that are geographically closer along the latitudinal gradient (KO & DE) and an increasing difference between chronologies along the longitudinal gradient. Although KO and PRE sites are close to each other and trees belong to the same age class, the low agreement between both site chronologies might be due to the slope aspect.

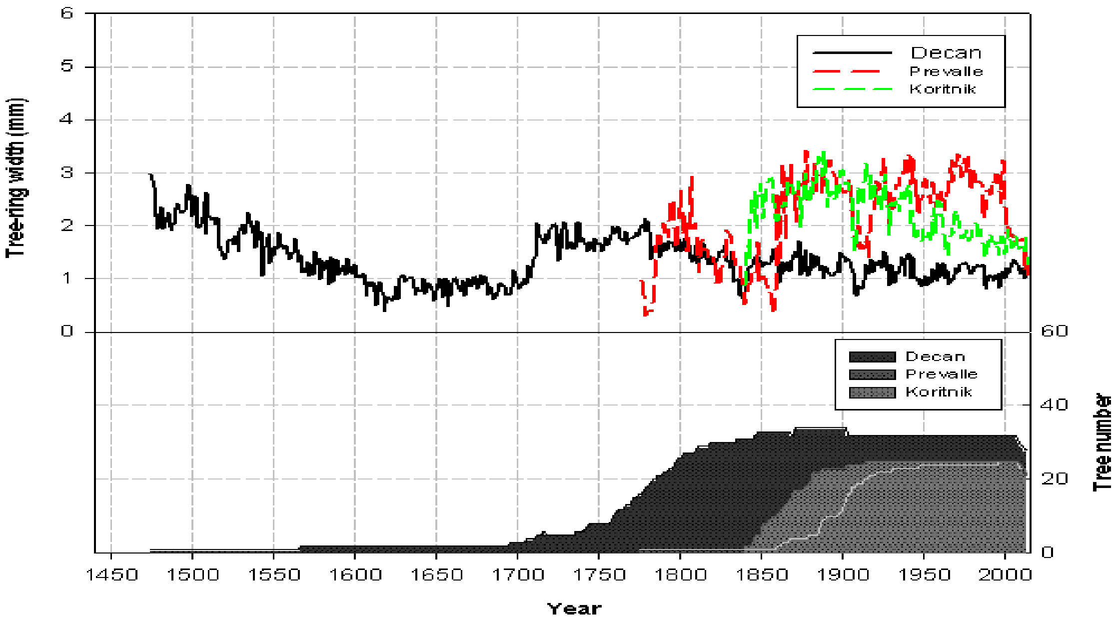


Figure 3. Raw tree-ring width chronologies of Bosnian pine (*P.heldreichii* Christ.) from Decani, Prevalla and Koritinik. Upper graph shows tree-ring width chronologies while below graph shows tree replication in respective site chronologies.

Table 2. Statistical parameters of three *P.heldreichii* chronologies from Kosovo

Code	Name	Period	No. of trees	Mean ring - width (mm)	MS	SD	AC1	EPS > 0.85
DE	Decan	1474-2014	34	1.06	0.224	0.498	0.769	1770
KOR	Koritnik	1840-2014	25	1.81	0.245	0.872	0.751	1876
PRE	Prevalle	1776-2014	25	2.13	0.212	0.907	0.783	1920

MS-Mean sensitivity; SD-standard deviation; AC1- first-order autocorrelation; EPS-expressed population signal

Table 3. Similarity coefficients between three *P.heldreichii* chronologies from Kosovo

Sampled sites	Similarity coefficients between chronologies											
	Decan				Prevalle				Koritnik			
	t-BP	GLK %	r	GL%	t-BP	GLK %	r	GL%	t-BP	GLK %	r	GL%
Decan	-	-	-	-	7.1	66	0.36	69	12.3	71	0.55	72
Prevalle	7.1	66	0.36	69	-	-	-	-	6.8	59	0.34	61
Koritnik	6.8	59	0.55	72	6.8	59	0.34	61	-	-	-	-

t-BP - t-value of Baillie-Pilcher; GLK% - Gleichläufigkeit; GL%- coefficient of convergence; r- coefficient of correlation

3.2. Growth-climate relationship

All correlations computed over the common period 1951 – 2013, from May prior to growth to the current October of ring-width formation were not high (maximum r-value: 0.37 for DE versus July precipitation) (Table 4a & 4b). From all 108 correlations calculated for temperature and precipitation together, only 16% reached the 95% significance level. These facts underline the existence of divergent correlation patterns among the three studied sites emphasizing the important role of local conditions on Bosnian pine's growth. Regarding to site-specific patterns, the DE chronology seemed to be slightly more sensitive to current summer precipitation variations than other sites. In case of KOR site, species growth was correlated negatively with temperatures of previous July, August and September as well as June of the current growing year. Moreover, growth-climate relationship showed that *P. heldreichii* growth was positively correlated with previous August and negatively associated with current May precipitation. The negative response to previous summer temperatures and the positive correlation to previous July precipitation suggests that *P. heldreichii* growth from KOR site is mainly controlled by drought conditions. Bootstrap correlation analysis showed that PRE chronology was positively correlated to the temperatures of current January and February and the precipitation of previous May, October and July of the current growing year. An adverse relationship was noted with previous June and current April precipitation. The main climatic factors stimulating growth in this high-elevation site were favorable temperatures during current winter associated with a positive water balance in July. Growth–climate relationships indicate that tree-ring formation in KOR and PRE sites does not depend on one single dominant factor, but rather on various combinations of precipitation and temperature in certain months resulting in a temporal alteration of climatic sensitivity.

Table 4a. Bootstrap correlation coefficients between residual chronologies and monthly mean temperatures for common period 1951-2013 from previous May to current October. Only significant correlations are shown.

	TEMPERATURE																	
	Previous year								**Current year**									
Site	may	jun	jul	aug	sep	oct	nov	dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Decani	▨							▨				▨						▨
Prevalla	▨	▨		▨			▨		**0.26**	**0.32**			▨	**-0.19**	▨			▨
Koritnik	▨	▨	▨	**-0.28**	▨		▨		**0.21**	**0.32**	**0.21**		**-0.20**	**-0.30**	▨	▨	▨	

□ **Positive correlation**
▨ **Negative correlation**

Table 4b. Bootstrap correlation coefficients between the residual chronologies and monthly precipitation sums for the common period 1951-2013, from previous May to current October. Only significant correlations are shown.

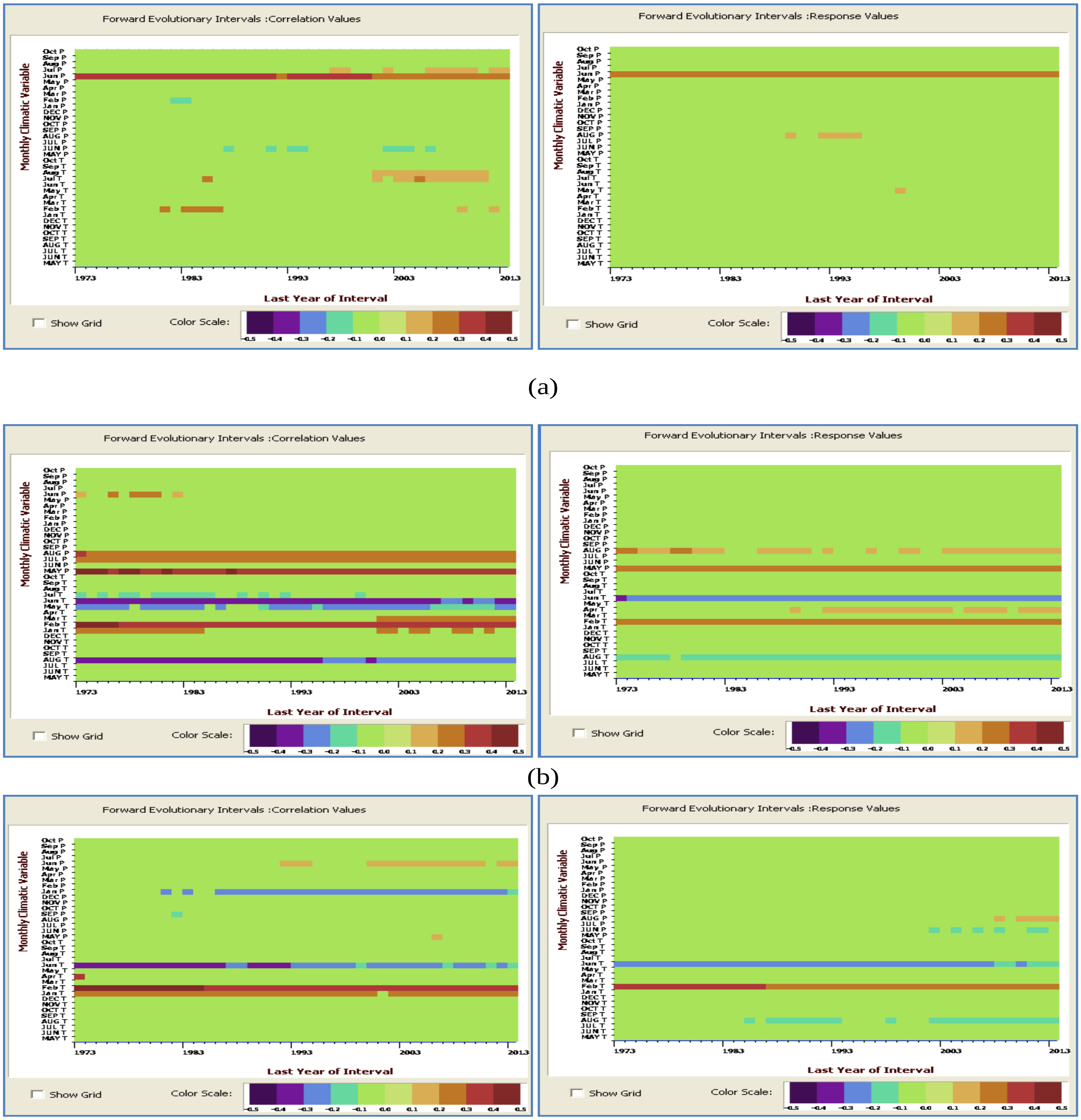
	PRECIPITATION																	
	Previous year								**Current year**									
Site	may	jun	jul	aug	sep	oct	nov	dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Decani		**-0.20**			▨				▨	**-0.16**	▨	▨		**0.29**			▨	▨
Prevalla		▨	▨		▨				**-0.19**	▨	▨	▨	▨	**0.17**		▨		
Koritnik	**0.30**	▨	**0.24**	**0.24**					▨	▨								▨

☐ **Positive correlation**
▨ **Negative correlation**

3.3. Temporal stability and spatial strength of Bosnian pine radial growth

We explored the temporal stability and the spatial strength of the relationship between ring- width chronologies and climate in the research sites (Figure 4).

FEI indicated a sustained negative relationship between radial growth with current June and previous August monthly mean temperatures for KOR and PRE sites, as well as a continuous positive relationship between growth and current February temperatures. FEI indicated the presence of a persistent positive relationship between species growth and previous May, July and August monthly precipitation at KOR site and current June at DE site. Regional signal evaluated by KNMI Climate Explorer (Figure 5), seems to be stable on a wide regional scale. PRE and KOR chronologies showed a wider regional strength with winter temperatures and a typical Ballkan strength for June temperatures. DE chronology showed a stronger strength with February temperatures and a smaller outreach for early spring temperatures extended from Ballkan to Russia. It was the only chronology which showed positive correlation with June precipitation but the chronology strength has an outreach from Croatia to Turkey. These results indicate that our Bosnian pine chronologies can be potentially cross-dated with neighbor chronologies from Balkan countries and southern Italy, covering the entire natural distribution range.

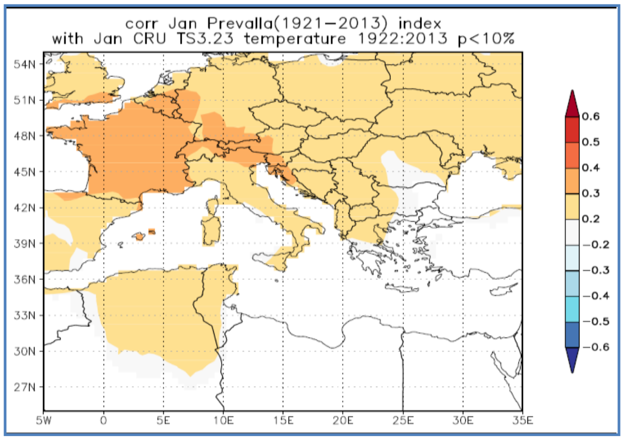


(a)

(b)

(c)

Figure 4. Results for forward evolutionary interval analysis (1921–2013) between monthly mean temperature and the Bosnian pine chronologies (32-year base interval) for DE (a); KOR (b) and PRE (c) sites. Monthly climatic variables are shown on the y-axis, beginning with the previous May and ending with current October. The last years of the forward intervals are listed on the x-axis. Significant positive ($P < 0.05$) correlations are shown with colors range from brown to cherish, while significant negative ($P < 0.05$) correlations are shown with color from green to purple.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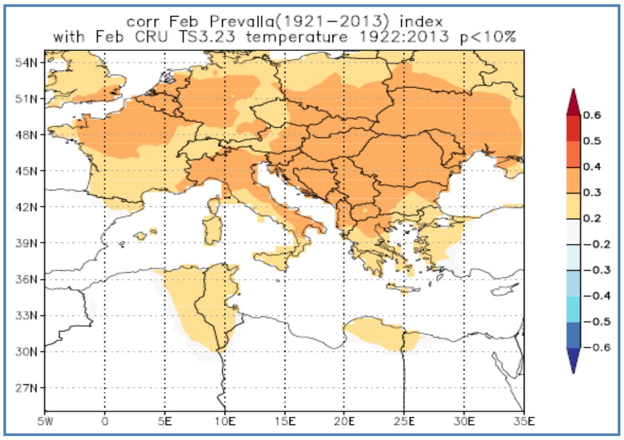
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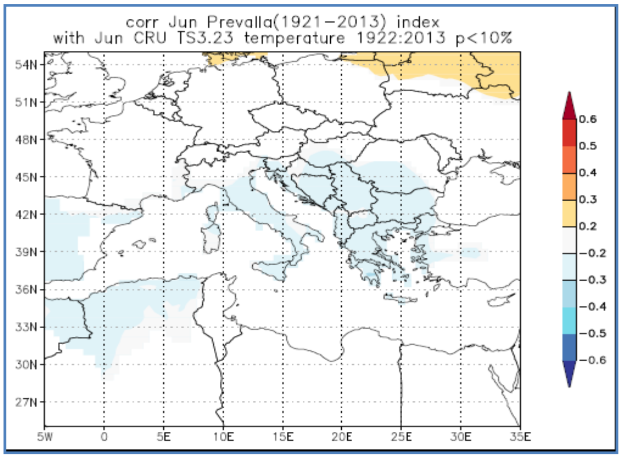
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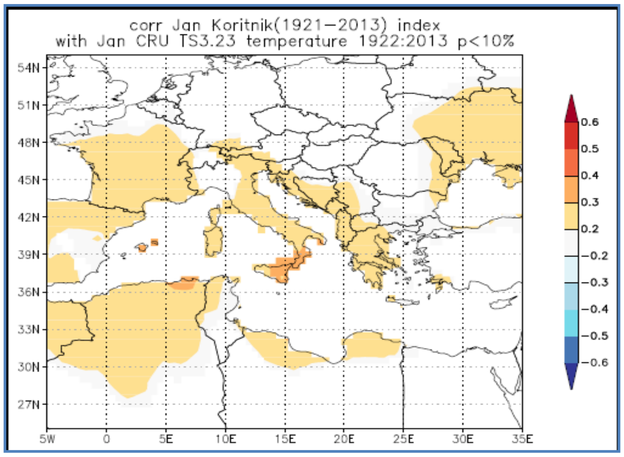
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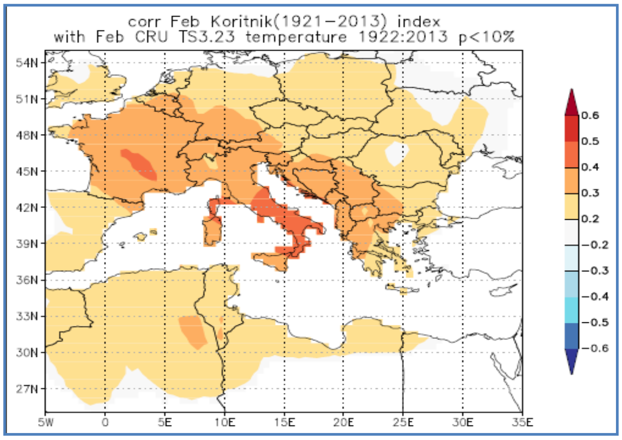
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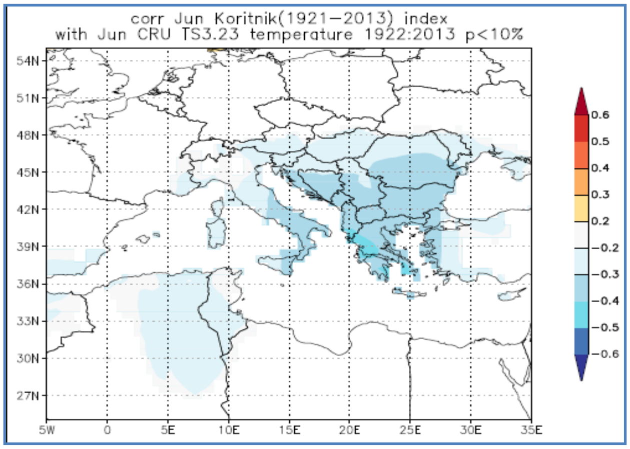
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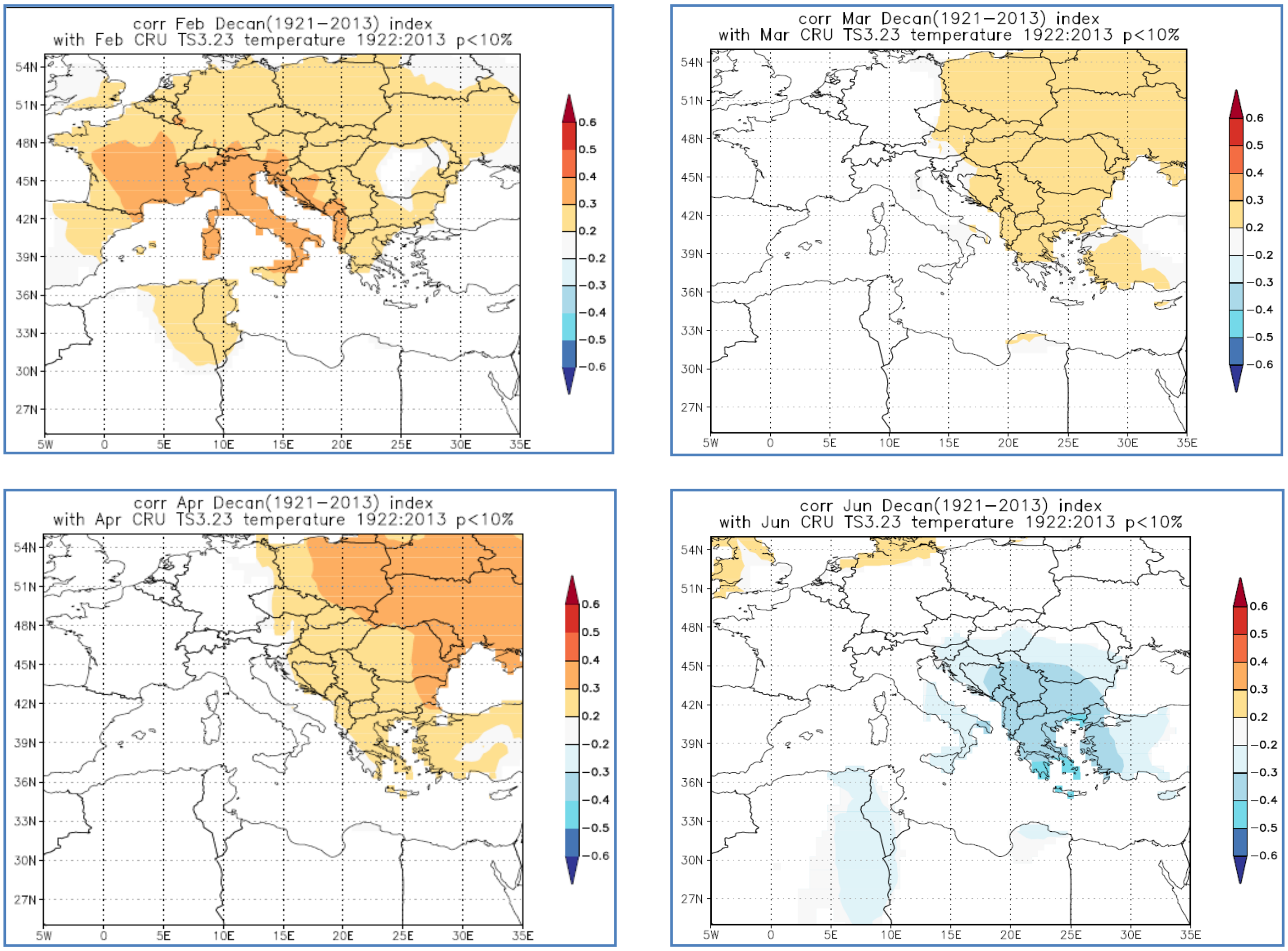

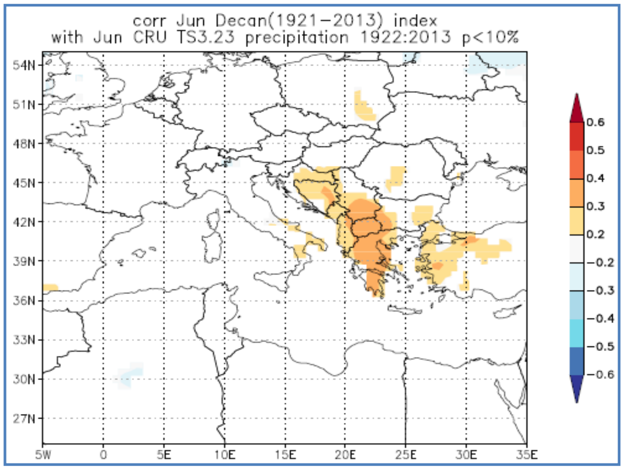

Figure 5. Spatial correlations, using KNMI Climate Explorer, between residual tree-ring chronologies and gridded climate data showing regional strength of the signal in radial growth.

4. Discussion and conclusion

In this paper we provided a description of the spatial and temporal patterns of *P.heldreichii* radial growth and how these patterns are related to temperature and precipitation data in the research area. We developed

3 tree-ring width chronologies of Bosnian pine reaching a maximum of 541 years back in time (from 1474 to 2014), from 98 trees located in high-elevation sites covering the natural distribution range of this species in Kosovo. These are the first chronologies from Kosovo, but there are also some other built earlier in Italy and the Balkan Peninsula. In comparison, the longest nearby *P. heldreichii* chronologies span periods of 1392 years (617-2008) were found in Albania (Seim et.al., 2012), 762 years (1243 to 2004) in Greece (Kuniholm and Striker 1983), 758 years (1250 to 2008) in Bulgaria (Panayotov et.al., 2010), and 827 years (1148 to 1974) in Southern Italy (Serre-Bachet, 1985). In our dataset, MTRW, tree-ring variability and AC1 increased significantly towards the east. MS also increases towards the south and AC1 towards lower elevations. The common increase in ring-width during the second half of the twentieth century noted at all final chronologies due to temperature change has been reported earlier (D'Arrigo et.al., 2008; Esper et.al., 2008; Oberhuber et.al., 2008). All chronologies were correlated ($p < 0.01$) with each-other and the level of agreement between them resulted to be unrelated to the vicinity of the sites. The temporal relationships between *P.heldreichii* growth and climate were not particularly robust. The low correlation values between residual site chronologies and climate could be related to the sparse availability of regional meteorological station data for Kosovo high-elevation sites resulting in a limited representation of the gridded CRU data for the study region. Even for the western Mediterranean basin, similar results based on three conifer species from the Pyrenees were reported (Buntgen et.al., 2010).

We found strong relationships between tree-ring chronologies and summer precipitation of the current growing year for DE and July precipitation for PRE site. The strong relationship between KO residual chronology and climate of the year prior to the growth indicates that favor previous winter conditions influence the early beginning of the cambial activity and tracheid formation in the next growing year due to the presence of enough available resources (Rossi et.al., 2006). We noted a age-dependent relationship between *P.heldreichii* and precipitation because the youngest trees from KO site were more sensitive to summer drought stress. The residual chronology from KO-site was negatively correlated with June temperatures and an inverse relationship was reached with July and August precipitation. Previous studies have shown that the duration of wood formation in conifers was shorter in old than in young trees (Carrer and Urbinati 2004). One possible explanation is the earlier onset of xylogenesis in young trees because the base of the stem is closer to the crown and hence to the source of auxin than in old trees (Rossi et.al., 2008).

Positive correlations with current winter temperatures reported at all three sites indicate that mild winters have a positive influence on snow melting or rainfall. From a physiological point of view, winter temperatures cannot directly influence cambial activity since the trees are dormant. However, during warmer winters, more precipitation falls as rainfall, rather than as snow (IPCC, 2007). In our case, it is more probable that precipitation in cases with warmer winter temperatures is in the form of wet snow. This can provide more soil moisture after snowmelt and could be a prerequisite for increased cambial activity given that other conditions are favorable. We expected a stronger thermal signal because the research sites were situated at high elevation and the low temperature is assumed to be the main driver for tree growth. Although sampling in Kosovo was conducted at the highest forested elevations (up to 1945 m a.s.l.), such sites do not represent typical tree-line conditions for this species. Previous studies reported the lack of a clear temperature controlled growth pattern in Mediterranean compared to the Alpine tree-line sites, therefore it's questionable if sampling at the upper zone provides more defined growth control (Korner, 1998).

The spatial relationships between *P.heldreichii* tree growth and climate show important variations in the relative importance of temperature and precipitation as key drivers of species radial growth. Our spatial analysis showed that *P.heldreichii* has a larger control than precipitation as indicated by the significant positive or negative correlations of this specie's growth with regional climate data. Chronologies from Prevalla and Koritnik sites showed a wide regional strength with winter temperatures and a typical Ballkan strength for June temperatures. Ongoing and future research focused on the analysis and integration of *P. heldreichii* growth along latitudinal and longitudinal transects, as well as on the spatial and temporal patterns of temperature and precipitation records and growth–climate relationships, from Kosovo, will improve the knowledge of long-term climate fluctuations during the last century. This research will provide a better understanding of climatic change at a wide range of spatial and temporal scales.

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