FORESTRY IDEAS, 2013, vol. 19, No 1 (45): 79–90

PINUS NIGRA ARN. TREE RING CHRONOLOGY FROM SLAVYANKA MTS. IN BULGARIA IS STRONGLY RELATED TO REGIONAL DROUGHT EVENTS

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Received: 05 April 2013 Accepted: 20 June 2013

Abstract

Black pine (*Pinus nigra* Arn.), also known as Austrian pine, is one of the widely used species for dendroclimatic analysis in the European region. Yet, studies for Bulgaria are still scarce and lack for Slavyanka Mts. The position of the mountain on the border of climatic regions, its nature-protection status and the high value of the local *Pinus nigra* variety, outline the importance to study in more details the relationship between radial growth and climate variability and evaluate tree growth in conditions of ongoing change. We composed tree ring width and latewood width chronologies following classic methodology and calculated correlations with climate series from Sandanski meteorological station. We found positive significant correlations with precipitation in early summer (r>0.4) and significant negative correlations with temperatures from the current and previous summers (r>0.43). Spatial correlations with September PDSI reveal strong positive correlation for wide area over the Balkan Peninsula. We consider that the local origin of *Pinus nigra* may be valuable for composing chronologies of summer drought events for the period without meteorological data.

Key words: tree ring chronologies, climate, precipitation, temperatures.

Introduction

Tree rings provide very good proxy records of past environmental conditions. This was successfully used for developing high-resolution climate reconstructions for periods prior to the existence of instrumental measurements. Yet, trees belonging to different subspecies and growing at different locations vary from one another in their response to ecological conditions. Climatic sensitivity of trees also changes through time (Leal et al. 2008). Because of the observed climate changes in many parts of the globe in recent decades, updating existing and composing new tree-ring chronologies is particularly valuable in evaluating potential changes in climate–tree growth responses during this period (Leal et al. 2008, Hughes et al. 2011). The Balkan Peninsula is one of the regions with highest climate vulnerability in Europe, but proxies are scarce for the area and this limits better understanding of long-term climate variability (Trouet et al. 2012).

A number of dendrochronological studies evaluate the *Pinus nigra* species as sensitive to climate variability (Strumia et al. 1997, Akkemik and Aras 2005, Leal et al. 2008, Köse et al. 2012a, Levanic et al. 2012, Poljansek et al. 2012). The tree

ring widths of *Pinus nigra* Arn. trees growing near the ecological limits for the species in the Vienna basin, Austria, showed strong and positive correlation with spring-summer precipitation (Leal et al. 2008). Studies from Turkey (Akkemik and Aras 2005, Köse et al. 2012a), Bosnia and Herzegovina (Poljansek et al. 2012) and Albania (Levanic and Toromani 2010) came to similar results. Amodei et al. (2013) studied the radial growth response to climate of three ecologically different populations of *Pinus nigra* ssp. *salzmannii* from the south of France. Proxy reconstructions of April–August (Akkemik and Aras 2005) and May-June precipitation (Köse et al. 2012b) were developed for Central and Western Turkey, respectively, by using *Pinus nigra* tree rings. For South-West Romania, a reconstruction of standardized precipitation index (SPI) indicating drought based of Black pine was made (Levanic et al. 2012). Wimmer et al. (2000) suggest that reconstruction of early growing season precipitation can be done with the use of false rings, formed by *Pinus nigra* trees from the Viennese basin. All these studies demonstrate well the suitability of Black pine for dendrochronological studies and especially for constructing proxy drought records.

Although there are many dendroclimatic studies on *Pinus nigra* for the western and central parts of the species' distribution area (Biondi 1992, Strumia et al. 1997, Richter et al. 1991, Fuster 2000, Leal et al. 2008, Andreu et al. 2008, Martin-Benito et al. 2008, Martin-Benito 2010) for the eastern parts of the range the studies are less. Yet, they have been progressing recently (e.g. Akkemik 2000, Hughes et al. 2001, Levanic and Toromani 2010, Poljansek et al. 2012, Köse et al., 2012a).

In Bulgaria dendrochronological studies of black pine were made for Western Rhodopes Mts. (Grozev and Nedelchev 1996) and Lozenska Mts. (Grozev and Yonov 1995). These early attempts demonstrated the suitability of local populations for tree ring analysis, but did not progress to long climate reconstructions. More substantial dendroclimatic analyses of this species' populations in the country still lack. For Slavyanka Mts., situated in the SW part of the country, there are no such studies yet.

The aim of this study is to determine the reaction of *Pinus nigra* trees in the region of Slavyanka Mts. to climatic conditions (temperatures and precipitation) and evaluate the suitability of the regional populations for climate reconstructions.

Material and Methods

Main characteristics and distribution of *Pinus nigra* in Bulgaria

Black pine (*Pinus nigra* Arn.) occurs in Central and South Europe and Southwest Asia. Trees of the species can be over 40 m high and up to 2 m in diameter and can reach ages of about 600 years (Richardson 2000). Tree ring boundaries in *Pinus nigra* wood are distinct with generally abrupt transition from earlywood to latewood. Occasionally false rings are observed in samples from lowland regions (Schoch et al. 2004). Missing or partially missing rings can occur in samples from sites with extreme conditions. The species is xerothermic and grows at altitudes between 400 and 1500 m a.s.l. mainly in steep areas on different soil types. It is not shade tolerant and prefers warm con-

ditions. In Bulgaria is distributed *Pinus nigra* ssp. *pallasiana* (Roussakova and Valchev 2011). The species grows mostly on Rendzic Leptosols and Rendzinas on steep and often rocky slopes in the southern and western parts of the country. Local populations are well adapted to high summer temperatures and can resist low winter temperatures (Yurukov 2003). The local *Pinus nigra* ssp. *pallasiana* forests are classified as vulnerable habitat in the Red Data Book of Bulgaria.

Study Area

The studied trees are located near Goleshovo village in Slavyanka Mts., in Southwestern Bulgaria (Fig. 1). The diverse flora and fauna of the region define it as valuable from conservational point of view. Alibotush nature reserve, established in 1951 and declared a part of UNESCO's World Network of Biosphere Reserves in 1977, is situated in Slavyanka Mt.. The region of Slavyanka Mt. is also part of the ecological network of protected areas NATURA 2000.

The study area is at 1400 m a.s.l. Climate in the area is formed under strong Mediterranean influence. The precipitation maximum occurs in autumn and winter, while the summer is arid with high temperatures. Soils are mostly *Rendzic Leptosols* on limestone bedrock. They are thin and have low water holding capacity. Such combination of site conditions is expected to result in high sensitivity of the trees to available moisture and to minimize their sensitivity to non-climatic factors.

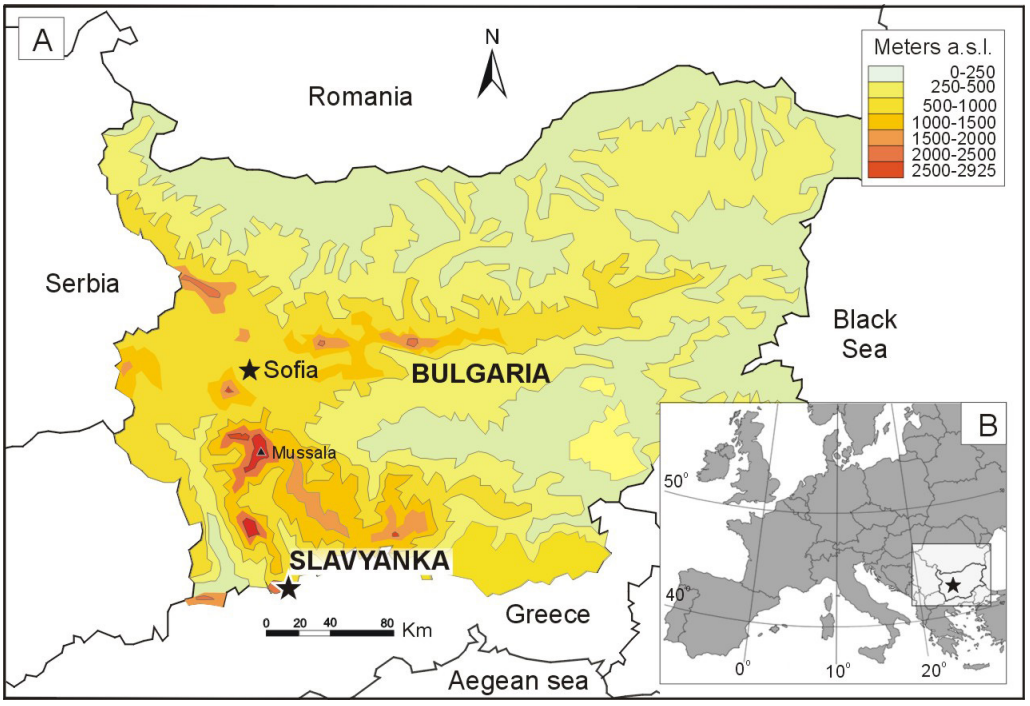

Fig. 1. Location of the study area.

Data collection and chronology development

We extracted 20 cores with increment borer at breast height from dominant trees. The cores were air-dried and mounted on wooden holders. After sanding with progressively finer sandpaper until the annual rings and tree ring morphology became clearly visible, all samples were scanned at 1200 dpi. Individual tree ring widths and latewood widths were measured with Cybis CooRecorder 7.3 software to the nearest 0.01 mm. The tree-ring width series were cross-dated both visually and with the software CDendro 7.3. The program COFECHA (Holmes 1983) was used for between-series correlation analysis and verification of measurement and cross-dating accuracy. The single tree-ring width series were standardized with ARSTAN (Cook 1985), using cubic smoothing splines with 50 % cutoff of 100 years for removal of age-related trend. This standardization method is data-adaptive and removes low-frequency signal from the series. Yet, the selected spline length preserves the decadal variability, which might be due to climate variations. Calculated series of index values were then used for building a standard chronology that does not contain age-dependent ring width variations. We also measured latewood widths and built a separate latewood chronology. Because the latewood chronology showed little low-frequency variance, we used the non-standardized (i.e. "raw") latewood chronology for the correlation analysis. We computed several statistical parameters commonly used in dendrochronology from the tree-ring width series. The mean sensitivity (MS) measures year-to-year variation in tree-ring width and is thus considered an estimate of the extent to which the chronology reflects local climate variation. The first order autocorrelation reflects the influence of previous year's growth on current growth. The expressed population signal (EPS) quantifies the degree to which the constructed chronology portrays the hypothetically perfect one (Wigley et al. 1984). We computed the EPS over 30-year windows lagged by 15 years and used an EPS value of 0.85 as a threshold for the reliability of our chronologies (Wigley et al. 1984).

We compared the standardized chronology from Slavyanka with other chronologies of the species from Bulgaria and the neighboring countries (Fig. 6). For the comparison we used a 266 years long (1741–2007) *Pinus nigra* chronology from Dobrostan region, Rhodopi Mts., Bulgaria, 1200 m a.s.l., (Shishkova and Panayotov 2013), 280 years (1730–2010) chronology from Baile Herculane, Romania, 1350 m a.s.l., (Levanic et al. 2012), 260 years (1750–2010) chronology from Bukonik, Albania, 900 m a.s.l., (Levanic and Toromani personal communication), 300 years (1719–2010) regional chronology from Bosnia and Herzegovina, 1500 m a.s.l. (Poljansek et al. 2012) and a 252 years (1751–2003) chronology from Scotida Forest, Greece, 1500 m a.s.l., (Kuniholm, International Tree-Ring Data Bank, ITRDB). We calculated *t* values and Glk values and Pearson's correlations to estimate the similarity between the chronologies.

We also checked for matching years with narrow rings in the studied chronology and other Pine chronologies from Bulgaria.

Climate data and climate-growth correlation analysis

Climate data was obtained from the meteorological station in the town of Sandanski, which is situated 32 km to the north-west

of the study area at 220 m a.s.l. The series are not homogenized, but verified and considered to be with high quality. Monthly precipitation sums and average monthly temperatures for the period 1931–2007 were used for comparison with the standard tree-ring width and the raw latewood width chronologies. We calculated Pearson's correlation coefficients between the chronologies and the climate series. In order to determine if the signal is temporally stable, we divided the data in two equally long sub-periods and calculated correlations for each of them. Correlation coefficients were considered significant if they exceeded absolute value of 0.235 for the whole period and 0.325 for the sub-periods.

We examined spatial correlations, using 0.5º x 0.5º gridded data of self-calibrating PDSI for the period 1901–2002 (van der Schrier et al. 2006). The PDSI index provides standardized value showing prolonged droughts and is frequently used in climate analysis (Palmer 1965). Maps were generated using the KNMI Climate Explorer (van Oldenborgh and Burgers 2005).

Table 1. Statistical and descriptive parameters of the tree-ring width chronology and the latewood chronology.

Parameter	TRW chronology	LW chronology
Length	160	160
First year	1848	1848
Last year	2007	2007
Number of series	20	20
Mean width, mm	1.63	0.49
Mean sensitivity (MS)	0.241	0.357
Autocorrelation (1st order)	0.853	0.622
Correlation between series	0.592	0.575

Used abbreviations: TRW – tree ring width; LW – latewood width.

Results

Tree-ring width chronology and a latewood width chronology were built out of 20 cores spanning the period 1848–2007 (Table 1). Latewood width was about 1/3 of the total tree ring width, which indicates that earlywood width has dominant effect over the whole tree ring width.

The raw tree ring width chronology has clear age effect with wider tree rings in earlier years and gradual decrease of the tree ring width (Fig. 2a). About 80–100 years after the establishment of most of the trees they started to have relatively stable growth with mostly year-to-year variations in tree ring width. The latewood width chronology does not show clear age effect. Both chronologies have relatively high 1-st order autocorrelation, which demonstrates serious influence also of the growth conditions from previous years. The mean sensitivity statistics is higher for the latewood width chronology, demonstrating higher year-to-year variation. The single series have very similar growth, which is demonstrated by the high between-series correlation (Table 1) and very high EPS values. They exceed the accepted threshold of 0.85 (Wigley et al. 1984) for the whole period (Fig. 2).

Correlations of tree ring width and latewood width series with temperatures and precipitation show strong and temporally

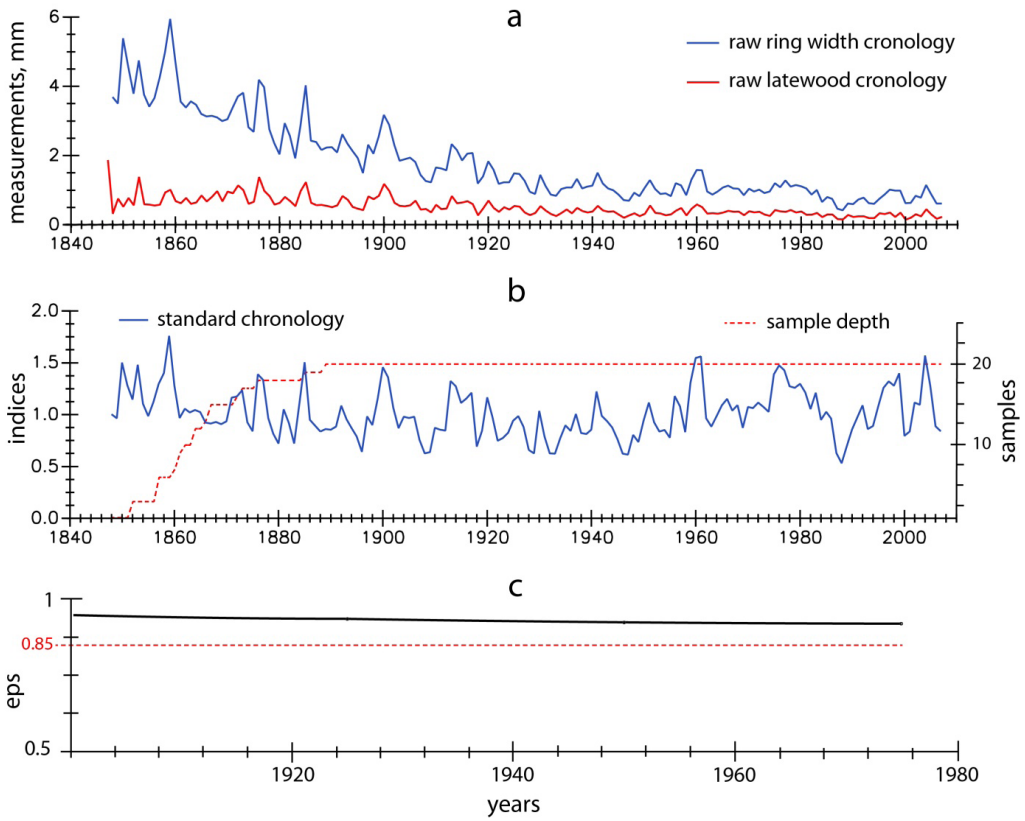

Fig. 2. Tree ring width and latewood width chronologies from *Pinus nigra* from Slavyanka Mts., Bulgaria: a – chronologies from averaged widths (raw chronologies); b – standardized chronology (blue solid curve) and number of used series (red dashed curve); c – EPS (black solid curve) of the standardized chronology.

stable effect of dry conditions in the summer period. The correlation between the TRW chronology and summer (July–August) and early autumn (September) temperatures of the previous year is negative and statistically significant (Fig. 3). Correlations with summer temperatures of the year of growth are also negative. Temporally most stable are the correlations with September temperatures from previous year (r=–0.43 for the whole period and r<–0.4 for the two sub-periods), July temperatures from growth year (r<–0.45 for the 1932–2007 period) and the averaged May–July temperatures (r=–0.44) of the growth year. Correlations with precipitation are positive for summer months of the year of growth and strongest for the May–July precipitation sums (r>0.45).

The relationship between latewood and climate conditions is similar (Fig. 4), but latewood width has slightly higher correlations with both July mean temperatures (r=–0.48) and May–July precipitation sums (r=0.54). The correlation coefficient between the latewood width chronology and September PDSI (r=0.57) is also very high. Spatial correlation shows

that this signal is strong (r>0.5) for the region of West Bulgaria, as well as for the middle and eastern parts of Macedonia and the northern parts of Greece (Fig. 5).

It is worth noting that for many of the months the correlation coefficients for the period 1971–2007 are stronger than for the period 1932–1970.

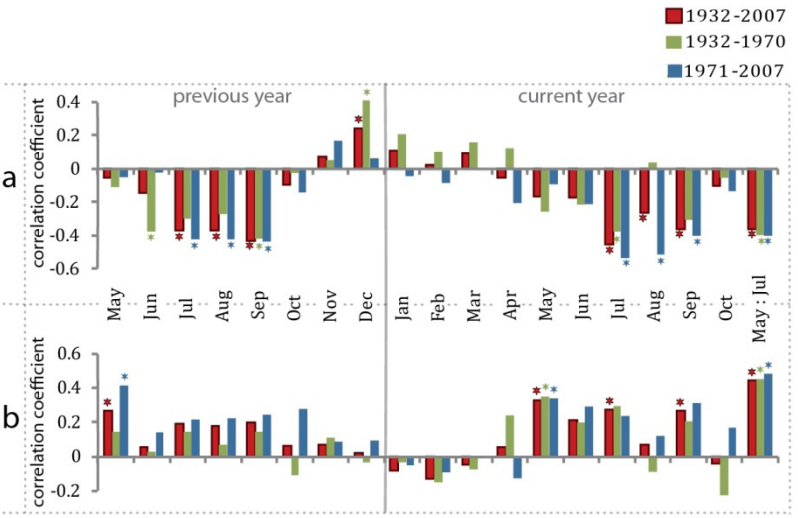

Fig. 3. Correlations between the standard tree-ring width chronology and: a – average monthly temperatures; b – monthly precipitation sums.

Note: Statistically significant values are marked with asterisk.

Years, in which narrow rings were produced, were 1880, 1883, 1896, 1908–09, 1918, 1928–29, 1946–47, 1984, 1987–88, 2000. Some of them match with negative pointer years from other studies of Black pine in the Western Rhodope Mts., Macedonian pine (*Pinus peuce* Griseb.) and Bosnian pine (*Pinus heldreichii* Christ.) in Pirin Mts. (1909, 1929, 1947, 2000) and Scots pine (*Pinus sylvestris* L.) in Vitosha Mountain (1918, 1988, 2000).

The comparison with other chronologies showed highest correlation with the one from Dobrostan, Bulgaria (r=0.63, t=6.8, Glk=0.62). It is the one with closest location (approx. 120 km to the north-east) and was influenced by similar

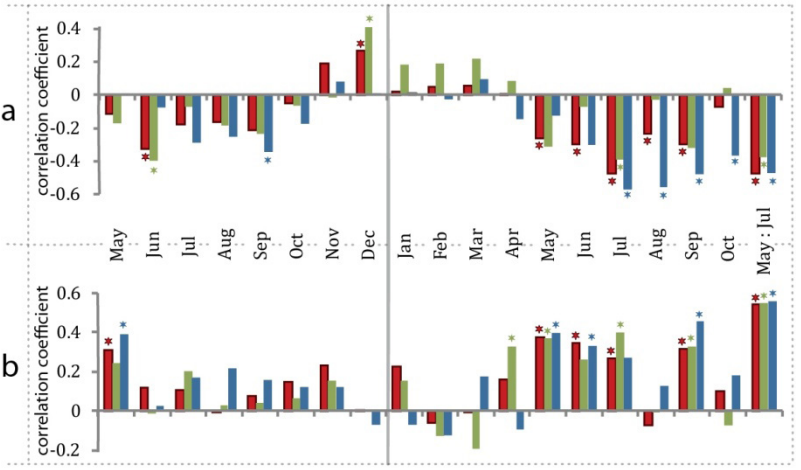

Fig. 4. Correlations between the latewood width chronology and: a – average monthly temperatures; b – monthly precipitation sums.

Note: Statistically significant values are marked with asterisk.

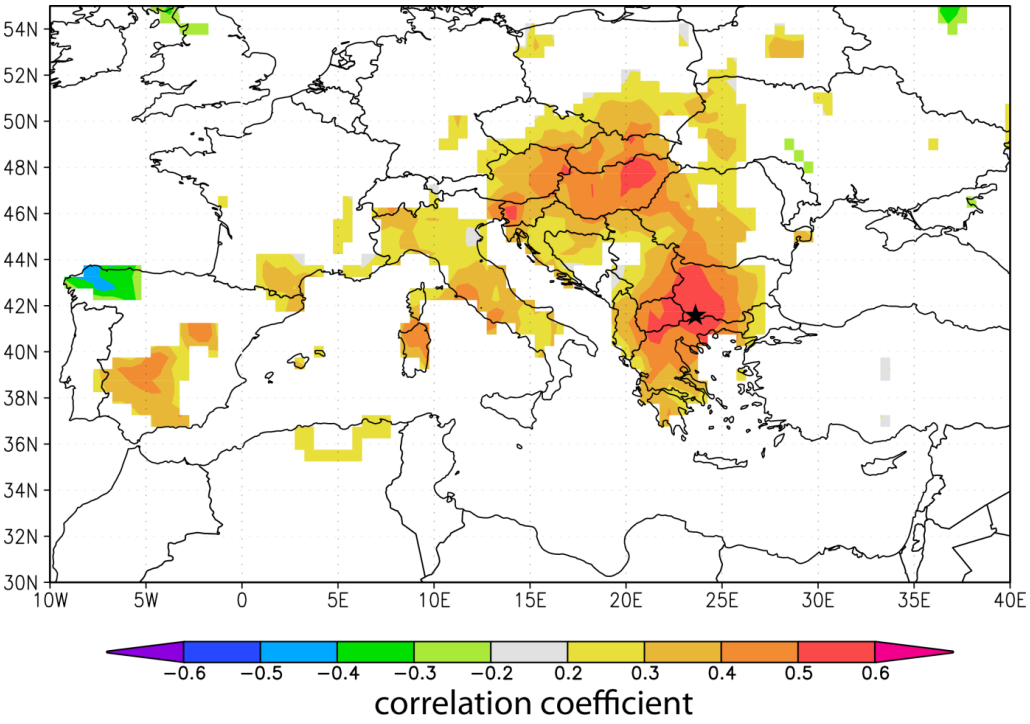

Fig. 5. Correlations between the latewood width chronology and September PDSI.

Note: The study site is marked with asterisk.

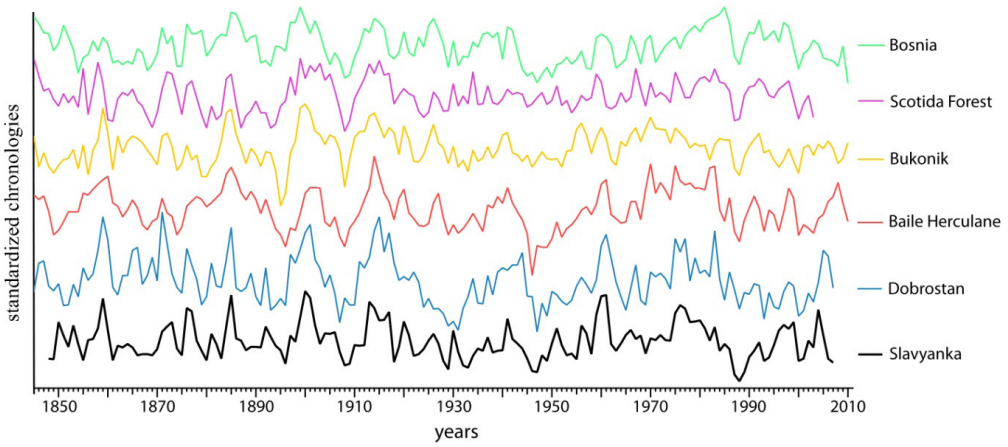

Fig. 6. The standardized *Pinus nigra* chronology from Slavyanka Mts., Bulgaria (black solid curve) compared to Black pine chronologies from Dobrostan (Bulgaria), Baile Herculane (Romania), Bukonik (Albania), Scotida Forest (Greece) and Bosnia and Herzegovina.

Note: Only the common period is shown on the graph.

climatic conditions to those of Slavyanka Mts. Also significant are the relations with the chronologies from Greece (*r*=0.54, *t*=7.07, *Glk*=0.63), Albania (*r*=0.58, *t*=7.1, *Glk*=0.7) and Romania (*r*=0.59, *t*=6.4, *Glk*=0.66). Correlation is lowest with the chronology from Bosnia and Herzegovina (*r*=0.49, *t*=6, *Glk*=0.66).

Discussion

High EPS and inter-series correlation suggest that the sampled trees reacted similarly to the factors influencing annual growth and the chronologies are suitable for climate-growth relationship analysis (Wigley et al. 1984).

Our results indicate that the studied trees are sensitive to the combination of high temperatures and low precipitation amounts in the growing season. This climate-growth relationship is typical for species, growing in conditions of moisture insufficiency (i.e. drought) and suggests it is useful to perform correlation analysis with drought indices (Fritts 1976). The high correlation with September PDSI demonstrates that indeed the dry conditions during the summer affect mostly the tree ring production. The effect of water shortage during summer months on tracheid formation may result from stressed due to moisture deficiency, general slowing down of physiological processes and finally production of fewer cells (Panayotov et al. 2013). Dry conditions can be a reason for reduction of cambial division and cell-wall thickening and earlier cessation of cambial activity. Because of drought, stressed trees may also allocate more carbon into reserves and favor root development, rather than use carbon to produce tracheid cells in the stem, resulting in fewer cells in tree rings and therefore formation of narrower tree rings (Martin-Benito et al. 2013).

Negative correlation between tree-ring widths and late summer and early autumn temperatures of the previous year may be explained by the fact that above average warmth in autumn (or late summer) of the previous year can prevent nutrient storage for the next year growing season and negatively influence the following year xylem functionality and therefore the produced tree ring (Levanic and Toromani 2010).

Latewood width is mainly influenced by conditions in late summer and early autumn because at that period take place the processes of production of new cells, that compose the latewood section of the tree ring and their transformation. For the region this is the period with lowest precipitation amounts. That is why the signal for regional drought events is stronger in latewood, than in tree-ring and earlywood widths. This is supported by the high correlation coefficient between latewood and September PDSI and is also confirmed by the significant spatial correlation. Because of this we assume there is a reason to consider latewood as more sensitive to drought and appropriate for climate reconstruction purpouses.

Our results correspond to those from other studies of *Pinus nigra* in Europe that characterize latewood as more sensitive to climate than earlywood (Lebourgeois 2000, Martin-Benito et al. 2013). A study from Southeastern Spain defines latewood as the most sensitive ring section, primarily influenced by current year precipitation, in trees from different crown classes (Martin-Benito et al. 2007).

Narrow rings, found in the chronology, are relevant to years associated with known years with dry summer conditions or preceded by dry periods, such as 1908, 1918, 1928, 1945–47, 1984–88, 2000

(Panayotov et al. 2013), which confirms the sensitivity to drought of the studied Black pine population.

The chronology can be complemented with other series from similar sites in the region, in order to increase its length and sample depth, which will make it more valuable for climate reconstructions.

The similarity of the studied chronology with others from the Balkan Peninsula is proof that it is representative of the conditions in the area and can be used in building a regional Black pine chronology.

Conclusions

This work characterizes the studied *Pinus nigra* chronology from Slavyanka Mts. in Southwest Bulgaria as sensitive to regional climate conditions. Earlywood and thus the entire tree ring width contain climate signal from previous year late-summer and autumn temperatures, whereas latewood width contain strong summer and early autumn drought signal, which is representative for the region. We consider that the chronology can be included in Black pine dendrochronological network for the region and used to study the past climate variability and especially drought events in Southeastern Europe.

Acknowledgments

We would like to thank Georgi Gogushev and Angel Dzhambazov for their help in the fieldwork. We are thankful for the comments of two anonymous reviewers, who improved the manuscript. This work was supported by project DTK 02/02/2010 of the National Science Fund of Bulgaria.

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