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EXTREME CLIMATE CONDITIONS IN BULGARIA – EVIDENCE FROM *PICEA ABIES* TREE-RINGS

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Abstract

Tree ring chronologies are one of the main sources of high-resolution proxy records for periods without instrumental climate data. Yet, for the territory of the Balkan Peninsula well-replicated chronologies are still limited in number and distribution. We studied pointer years in two high-mountain *Picea abies* tree ring chronologies from Bulgaria and their relationship with climate variability. We found that common negative pointer years (i.e. narrow tree rings) were associated with colder than average summers, but also with drier early summer periods. Some of the negative pointer years followed extremely cold preceding winter. Coinciding positive years were related to higher temperatures in August. Warmer than normal late-winter period in the SE part of Bulgaria also contributed to wider tree rings. Some of the years related to narrower tree rings were found to be with inverse climate situations in Central and Western Europe. This paper points out the potential to use high-mountain *Picea abies* chronologies to study past climate extremes on the Balkan Peninsula.

INTRODUCTION

Some of the best-preserved mountain ecosystems in Europe can be found in South-Eastern Europe. The Balkan range, Vitosha Mountain, Rila Mountains, the Rhodopes Mountains and Pirin Mountains in Bulgaria host centuries-old forests. These mountains are close to the borders of the range of some species. In such locations species demonstrate higher sensitivity to ecological conditions and especially to their extreme variations (Fritts, 1976). Due to this fact forests react distinctively to unusual climate events and periods. An example is the long drought in the 80s and early 90s in Bulgaria. It provoked the decline of coniferous afforestations on vast territories, especially at lower altitudes and was considered by some researchers as a triggering factor of deteriorating health status of mountain forests (Raev et al., 2003). While extreme events like these raise additional discussions on climate, possible climate change and the consequences from it, it is very hard to evaluate such processes due to the lack of long temperature and precipitation instrumental records. In this context it is increasingly important to construct reliable high-resolution proxy records and one of the main sources of such are dendrochronological series. Since tree ring formation is a reflection of the interaction between the tree and the surrounding environment (Fritts, 1976), tree rings often contain clues about the variation of environmental factors such as temperature and precipitation. Due to this especially trees growing at locations with limited resource availability (e.g. high mountain sites with low summer temperatures or low-altitude sites with limited precipitation) are a very good natural archive of past climate. Although numerous tree-ring chronologies from high elevation or latitude sites in Europe have been used to reconstruct past climate variability (Briffa et al., 2002; Esper et al., 2002; Mann, Jones, 2003; Esper et al., 2005; Büntgen et al., 2006), the attempts to cover the entire Balkan region with proxy records are limited (Xoplaki, 2001; Luterbacher, Xoplaki, 2003). To this moment available to the international scientific community are only several local tree-ring chronologies from Bulgaria and Romania (Raev et al., 1987; Raev et al., 1993; Vakarelov et al 2000; Panayotov, Yurukov, 2007; Popa, Kern 2009; Mirchev et al., 2009; Panayotov et al., 2010). Yet, the high need for proxy climate data is a prerequisite for increasing tree-ring studies in the region.

The objective of our study is to present and discuss the pointer years in tree-ring chronologies from mountains in Bulgaria and their associations with the climatic conditions. We have selected two chronologies from *Picea abies* (L.) Karst. They are representative for high mountain locations in Vitosha Mountains and Rila Mountains.

MATERIAL AND METHODS

The study sites were selected to be representative for sub-alpine Norway spruce sites. We studied one *Picea* site from Vitosha Mountain in Bulgaria (Bistrishko braniste Reserve, abbreviated 'P_BBR', 42º34´N, 23º18´E) and one from Rila Mountain (Parangalitsa Reserve, abbreviated 'P_PAR', 42º02´N, 23º23´E)m (Fig.1). Both Norway spruce chronologies are from the sub-alpine belt (e.g. above 1750 m a.s.l.). The chronology from Bistrishko braniste includes also trees from the local tree line (1850 – 1950 m). The chronology from Paragnalitsa is from a region, which is representative for optimal growth conditions for *Picea abies* (Raev et al., 1987).

The tree ring cores were collected at breast height (1.3 m) from dominant trees using increment borer, mounted on wooden boards, sanded and measured with precision of 0.01 mm. The tree-ring width series were visually cross-dated (Stokes, Smiley, 1968). Crossdating was additionally verified using COFECHA software (Holmes, 1983). The series were standardized with 37% smoothing splines using the ARSTAN software (Cook, 1985). In this way we removed the age-related growth trends and preserved the high-frequency climate signal. From these series we calculated the pointer values following the approach of Cropper (1979) with the equation:

$$Zi = ((x_i - Mw)/SDw)*1000$$

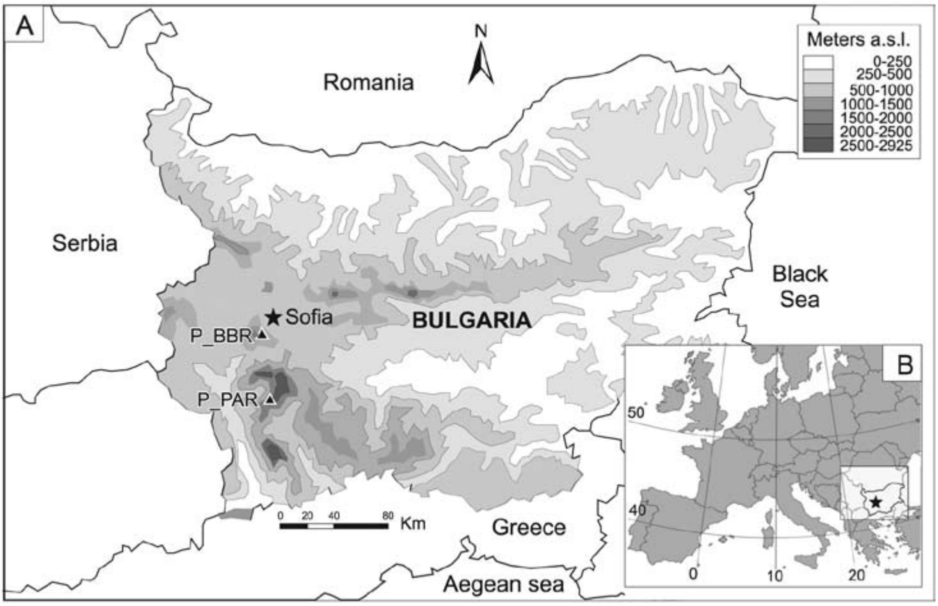

Fig. 1. Location of study sites

where Zi is the Cropper index; x_i is the standardized tree-ring value for a given year, Mw is mean tree-ring index for the period with which the year is compared and SDw is standard deviation of tree-ring indices for the same period. The length of the period against which each year was compared was 5 years.

As threshold values for detection of pointer years we used values of Zi of +/- 750 (Neuwirth et al., 2007).

Years were considered as common pointer ones for a given chronology if half of the cores displayed pointer years with values above or below the selected threshold.

For the climate analysis we used gridded monthly and seasonal temperature and precipitation fields for the period 1901-2006 from the CRU TS3.0 dataset (Mitchell et al. 2004). To compare our lists of pointer years with climate situations we performed composite analysis and generated maps using the KNMI Climate Explorer server (Oldenborgh, Burgers 2005; http://climexp.knmi.nl.)

RESULTS

Our chronologies cover mainly the last two centuries (Table 1). The longer one is Parangalitsa chronology (258 years), the shortest is from Bistrishko branishte. The chronologies consist of 49 to 64 samples. The EPS values, which are a measure of the common signal in the chronology and thus the reliability for climate-growth analysis (Wigley et al., 1984), reach the threshold value of 0.85 in the periods with good replication (Table. 1)

Table 1
Main tree-ring width chronologies statistical and descriptive parameters

Chronology name	Year span	First year	Last year	No. of series	Mean ring width (mm)	EPS above 0.85, year	Mean sensitivity
P_BBR	135	1870	2005	64	1.25	1883	0.23
P_PAR	258	1751	2008	49	1.57	1810	0.17

We found 18 pointer years in Bistrishko braniste chronology, of which 50% were negative. In Parangalitsa chronology there were 43 pointer years, out of which 84% were negative. In 8 cases a negative pointer year was followed by a positive in the next year. Negative pointer years, which coincided in *Picea abies* chronologies in their common period (e.g. after 1870) were 1876, 1926, 1943, 1949, 1963, 1976 and 1989 (Fig. 2). Common positive were 1927, 1945 and 2001. Many of the pointer years in one of the chronologies were not matched in the other.

Remarkable pointer years, in which high percentage of the cores displayed pointer values (e.g. Zi below or above 750) were found in both chronologies. In Parangalitsa chronology more than 70% of the trees displayed negative values in 1818, 1854, 1869, 1923, 1929, 1933 and 1943, while more than 60% in 1868, 1880, 1884, 1906, 1913, 1949, 1964 and 1976. High was also the number with highly common positive values – e.g. above 70% of the trees in 1786, 1814, 1852, 1927, 1931 and 1956 and above 60% in 1794, 1802, 1862 and 1950. Although the spruce chronology from Bistrishko braniste Reserve (P_BBR) consists of more treeline trees and thus is expected to be more sensitive to climate extremes and have more frequent common pointer years between all

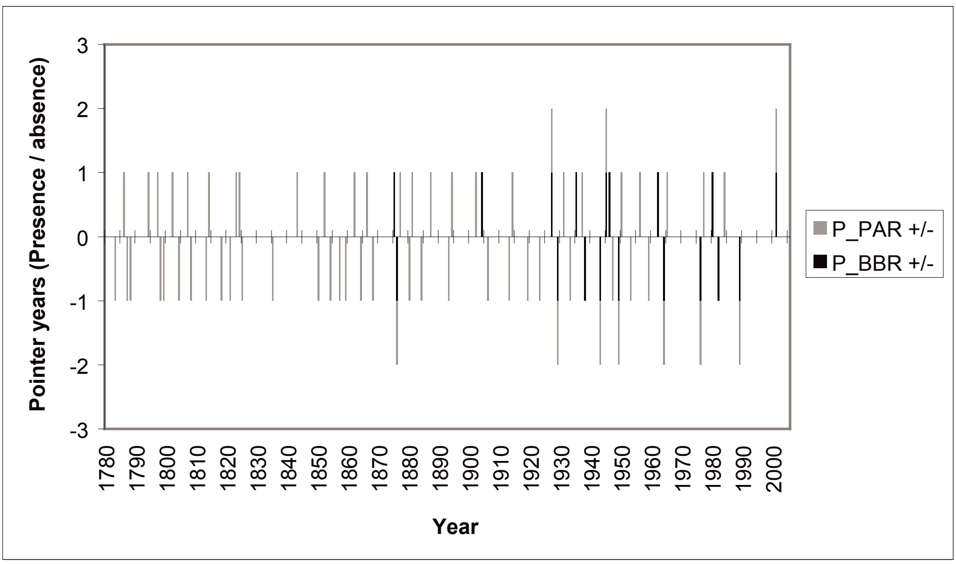

Fig. 2. Pointer years in *Picea abies* chronologies from high mountain locations from Bulgaria

trees, fewer years in it may be listed as such. Only in 3 years more than 60% of the trees displayed a negative value – e.g. in 1929, 1976 and 1982 and only in 2 years the case was such with positive values – e.g. in 1962 and 2001.

Our composite analysis shoed that common negative *Picea abies* pointer years were associated with climate situations with colder summers (Fig. 3A), but also with drier early summer periods (Fig. 3B). Coinciding positive years were related to warmer than average August (Fig. 3D). Warmer than normal late-winter period in the South-eastern part of Bulgaria may also be contributing to wider tree rings (Fig. 3C). A direct comparison with temperature maps in the strongest negative pointer years reveals that in most of the cases (i.e. 1906, 1913, 1933, 1949, 1976) there was anomaly in summer temperatures. They were 2 to 3 degrees lower than the overall average for the 1901-2006

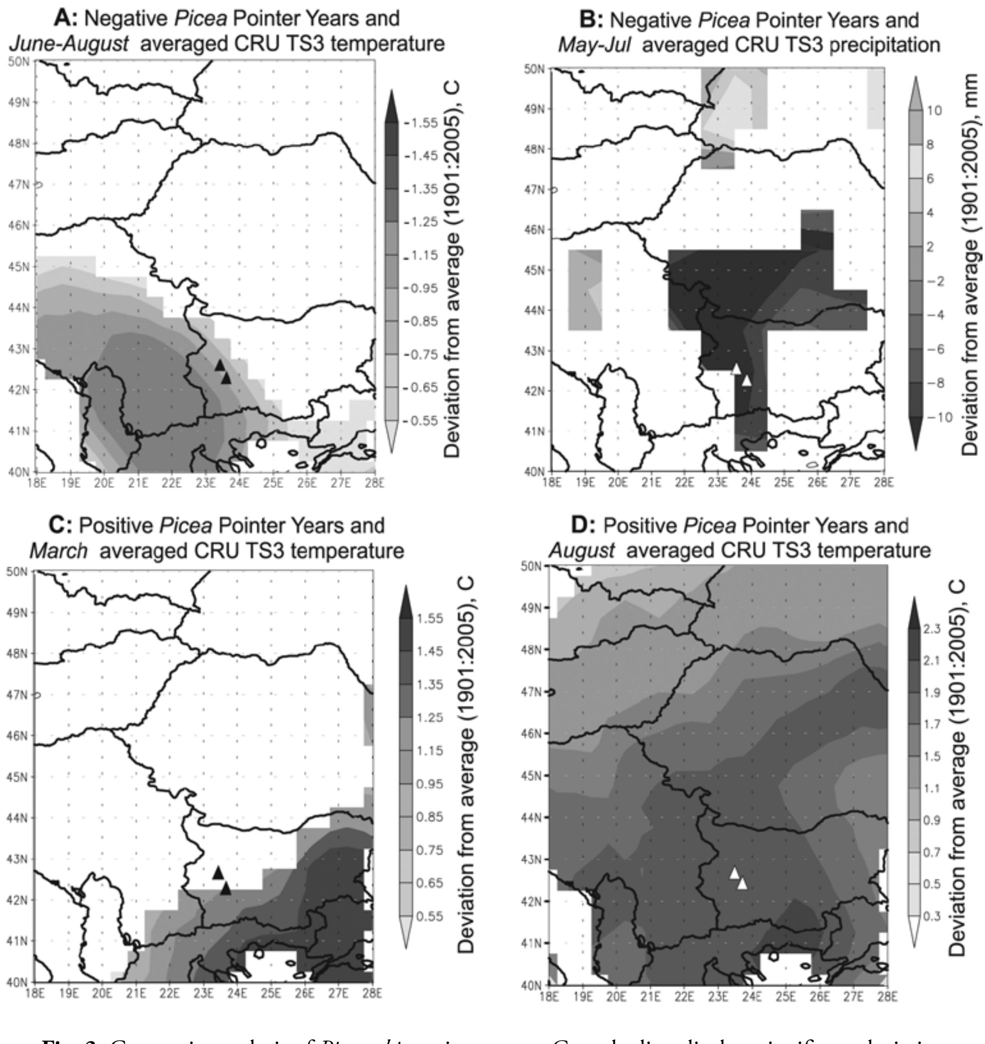

Fig. 3. Composite analysis of *Picea abies* pointer years. Gray shading displays significant deviations from the average (1901-2006) values

period (Fig. 4). If the standard in climate analysis period 1961-1990 is used as a basis, the differences are higher. Yet, in some of the most common negative pointer years (i.e. 1929, 1943, 1949 and 1964) there was unusually cold winter period in all of Black sea region or at least close to the SW border of the sea (i.e. Bulgaria and Turkey). While in most of these cases the deviations from the average were about 2 degrees Celsius, in 1929 they were of up to 5 degrees. In two of these years (1943 and 1949) the unusually cold winters were followed by warmer summers.

Another interesting observation is that in many of these extreme years there were inverse anomalies in Central Europe. Among the most impressive examples is the winter of 1943 and summer of 1976. The 1976 summer was unusually warm and dry in Central Europe, but in contrast it was the coldest year in Bulgarian Mountains (recording period 1933-2005) and additionally with much higher than average precipitation in June-August period (Panayotov, Yurukov, 2007). Besides narrow rings in the tree ring chronologies, it additionally caused production of light tree rings (Panayotov, 2005; Panayotov, Yurukov, 2007). We made this review of climate situations only for the period with more regular

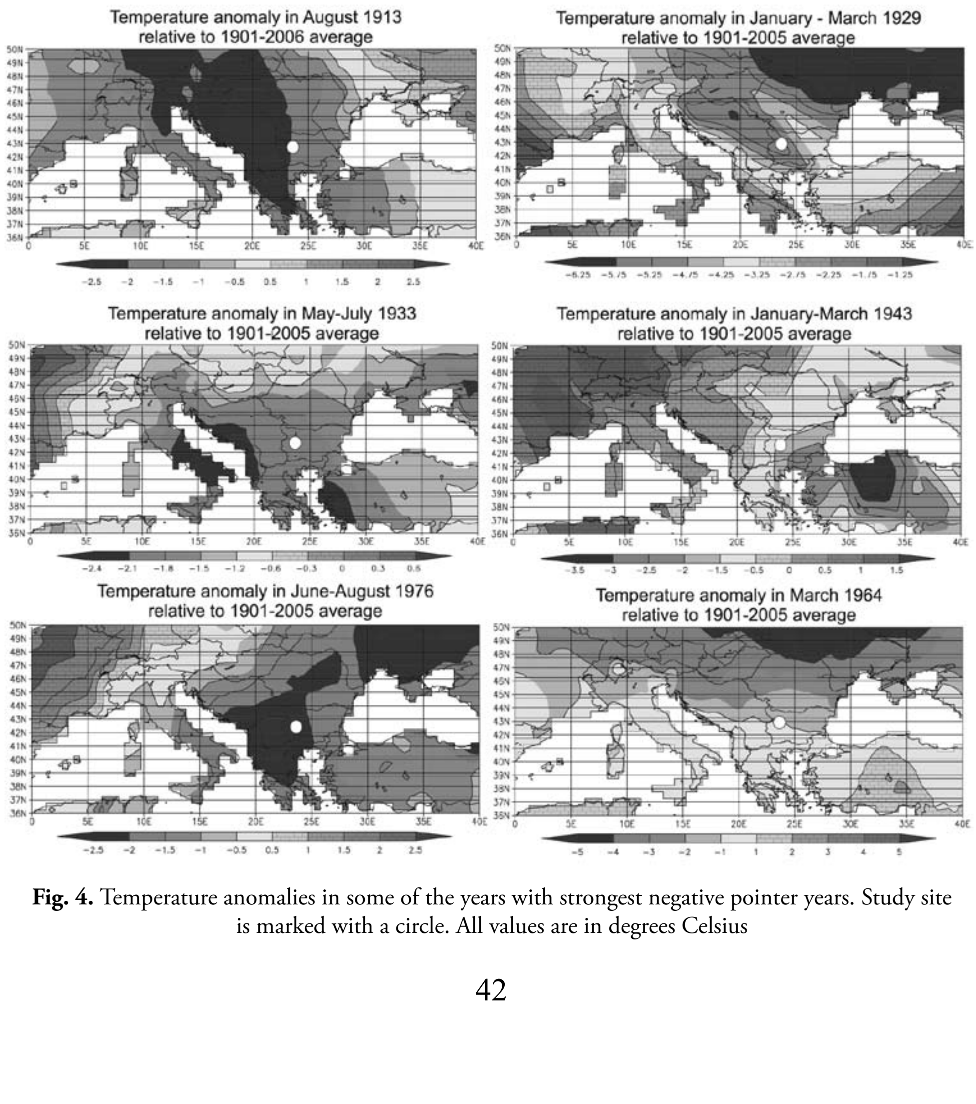

Fig. 4. Temperature anomalies in some of the years with strongest negative pointer years. Study site is marked with a circle. All values are in degrees Celsius

climate observations (i.e. after 1901) in the region. A comparison for a longer period it is possible only for specific smaller regions, in which climate observations were started earlier. Yet, we consider that at this stage of our work it would be better to focus only on available instrumental data and not on proxy reconstructions.

DISCUSSION

The analysed *Picea abies* chronologies are from sub-alpine locations and thus are subjected to lower temperatures and shorter duration of the vegetation period. Thus the finding that some of the negative pointer years were associated with colder than usual summers is expected. Such results have been received in the analysis of other Norway spruce tree-ring series in Europe (Neuwirth et al., 2007; Buntgen et al., 2006). It is also known that the growth of trees close to treeline is limited mainly by low summer temperatures (Tranquillini, 1979; Korner, 1998). More surprising result is that drier early summer periods can also be the reason for negative pointer years. A possible explanation is that decreased early-summer precipitation may cause unavailability of the needed quantities of moisture at the period when cell division is most active. Detailed studies of the processes of tree ring formation have shown that June is the month with most active wood formation at treeline locations (Rossi et al., 2006). Therefore we consider that a drought-type stress at that period could cause production of narrower earlywood and thus tree rings. In our *Picea abies* site in Bistrishko braniste some of the trees are growing on shallower soils formed above large spherical rock blocks, which can be the reason for draining of the soil profile in cases with extended periods without sufficient moisture supplies by snowfalls or rains (Panayotov, 2006). This can explain a 'drought-type' reaction of some of the trees.

Surprising is also the finding that Parangalitsa chronology showed more pointer years (including for the same period) than Bistrishko braniste one, although the sensitivity of Parangalitsa chronology is lower (Table 1). Normally expected is that treeline trees should be more climate-stressed and display more pointer years. Yet, one possibility is that trees with continuous limitation in availability of growth resources (including lower temperatures) may be more adapted to situations with unfavourable climate and thus react with lower magnitude. On opposite, trees growing at sites with favourable climate may be more stressed in an extreme situation (for example unusually cold summer) and therefore more trees can produce a narrow tree ring (i.e. a pointer year).

The finding that unusually cold winter periods in Black sea region might be associated with production of narrow tree rings is also novel. While very cold periods even during the dormancy period might be a reason for needle and fine-root tissue harming (Tranquillini, 1979) and therefore limit indirectly the consequent cambial activity, more detailed physiological studies are needed to fully understand the mechanism of such growth limitation.

The verification of our Norway spruce pointer years against the historical temperature reconstructions of Lutabaher et al. (2004) revealed that although unusual values were found for some years in the proxy record (e.g. 1802, 1818, 1852, 1854, 1869) for other years there was nothing unusual. The possible reasons are two – either the pointer years in our *Picea* chronologies were not induced by climate extremes, or the spatial coverage of the data and proxy records on which the historical reconstruction was based was not good enough to produce a representative picture for the interior Balkan region. Since these years were repeated in high number of trees we consider, that the second option is more probable – e.g. there were unusual climate situations but the historical reconstruction failed to show them. Because long historical records and reliable proxy reconstructions are not yet readily available for large parts of the Balkans (Xoplaki et al., 2001), the reconstruction fields were probably based on averaging of data from longer distances (e.g. the coastal areas of Greece, Croatia, the Alpine region and Russia). Yet, in many years climate especially in South-east Europe may differ considerably from that of other regions of Europe. Good examples are recent extremes in Central Europe, which were either not that strong in Balkan Peninsula (i.e. the heat waves of 2003 and 2006) or even were opposite (i.e. the unusually dry summer of 1976 in Central Europe, which was one of the coldest for the century in the mountains of Bulgaria). This demonstrates that reliable proxy records from Bulgaria and neighbouring countries are urgently needed. Moreover, they should be of species with strong reactions against a specific and different climate anomaly – i. e. summer temperatures or droughts.

CONCLUSIONS

We found that years with anomalies in summer temperatures influenced *Picea abies* tree ring production at high altitude sites in Bulgaria and resulted in common narrow or wide tree rings. Negative pointer years were associated with colder summers but also with unusually dry early summer periods. Wide tree rings were produced in years with higher August temperatures and in some cases warmer late-winter period. We consider that our results demonstrate that pointer years in *Picea* chronologies from Bulgaria can be used to study climate extremes for periods, in which instrumental meteorological measurements were not available, but were covered by tree ring chronologies. Yet, further work is needed to confirm and clarify some of the surprising results. Additionally our findings have to be verified for larger territories. Thus regional knowledge for the spatial extent of climate extremes may be obtained.

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