Pinus peuce and *Pinus heldreichii* tree rings as a key to past mountain climate in Southeastern Europe

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Introduction

High mountain ecosystems are among the most sensitive to environmental changes (Lloyd 1997, Körner 1998, Moiseev 2002, Camarrero & Guitierrez 2003, Esper & Schweingruber 2004). This is one of the reasons, why many studies on climate and climate change have been focused on treeline forests. For this purpose among the frequently used research methods are dendroecological (Fritts 1976, Schweinguber 1996, Briffa et al. 2001). They are based on the fact, that tree ring formation is strongly dependent on environmental factors and especially on the varying temperature and precipitation (Fritts 1976). Trees in high mountains are growing at limiting temperatures and thus are very sensitive to general variation of temperatures and extreme climate events (Fritts 1976, Tranquillini 1979, Schweingruber 1996, Frank et al. 2005). This, together with the fact that once formed, tree rings do not change with time, makes tree-ring chronologies a “natural archive”, containing information on past climate and historical development of individual sites. In the last decades numerous proxy climate reconstructions based on treeline sites from high elevation and northern environments, have been created for various parts of the world (e.g., Briffa 2000, Esper et al. 2002, Cook et al. 2004, D’Arrigo et al. 2006). Yet, there are still regions, which are particularly important from ecological and climatic point of view, for which long tree-ring chronologies have not been constructed or are scarce. One of these is the Balkan peninsula. Despite its great importance as a border between the Mediterranean and Central European climate zones and the existence of numerous centuries-old forests (Griffiths et al. 2004), still only few attempts to construct long tree-ring chronologies from high mountains have been made (Vakarelov et. al. 2001, Panayotov & Yurukov 2007a, b, Popa & Kern 2008).

The objective of the present report is to present and discuss two tree-ring chronologies from a high mountain location in Pirin Mountains, Southwestern Bulgaria. One is a 655 years long series from Bosnian pine (*Pinus heldreichii* Christ) and the other is a 305 years long series from Macedonian pine (*Pinus peuce* Griseb.). The study sites are located at the same valley, but on opposite slopes. This enables the simultaneous analysis of chronologies composed of trees that are subject to different micro-site conditions, but to the same general climate variability. Despite the long life span of the species and the very suitable locations of the forests for dendro-climatic studies, only few attempts to construct and analyze tree-ring chronologies have been made up to now (Vakarelov et. al. 2001, Panayotov & Yurukov 2007a, b). Also, some of the conclusions for certain time periods based on them are not consistent with each other. Thus, in order to enable the use of these species for proxy climate reconstructions, a necessary step is to study carefully trees’ response to the climate elements especially in the context of micro-site conditions. We present the first simultaneous analysis of the reaction of *Pinus heldreichii* and *Pinus peuce* trees growing at close locations to the same temperature and precipitation regime.

Material and methods

The study area is situated in Bunderitca valley in the Pirin Mountains, Bulgaria, 41˚45′ N, 23˚26′ E (Fig. 1). The *Pinus peuce* trees are located on the North-Western slope of Todorka peak in the treeline belt (2100-2300 m a.s.l.). The *Pinus heldreichii* trees are on the Eastern slope of Vihren peak, from 1950 m to 2200 m a.s.l. Since the slopes are steep and hardly accessible, the forests have not been subjected to intensive logging or deliberate firing by shepherds in the past. Thus, these ecosystems can be regarded as natural. According to the Oliver & Larson (1990) classification, the forests are at the old-growth stage. The *Pinus peuce* trees grow on Umbric and Modic Cambisols formed on granite bedrock, while the *Pinus heldreichii* grow on Rendzic Leptosols and Regosols formed on marble bedrock.

Figure 1: Geographic position of the study area

The climate data for the analysis was obtained from Bansko (936 m a.s.l.) and Vihren chalet (1970 m a.s.l.) climate stations. The first one is at the foot of the mountain, 10 km off the study area and provides continuous record for more than 70 years (since 1931). The second is in the study valley, but operated for duration of just 25 years and therefore the record is useful mainly for average data and precise information about extreme climate situations. The climate in the region is typically mountainous, with strong influence of the Mediterranean air masses. The mean annual temperature (Vihren chalet climate station, 1970 m a.s.l.) is 3.5°C. It ranges from a mean monthly temperature of -4.7°C in January to +12.2°C in August. The annual temperature at the treeline, obtained by extrapolation, is 1.6°C, the highest average monthly temperature is 10.2°C. This coincides with the expected values of nearly 10°C in the warmest month at the treeline (Tranquillini 1979, Dakov et al. 1980, Körner 1998). The annual precipitation amounts to 1378 mm, with a maximum in autumn and winter. Deep snow covers are characteristic for the region. Mention deserves the fact that the absolute maximum snow depth for Bulgaria (472 cm) was recorded at the Vihren chalet station. At the same time the summer precipitation minimum combined with shallow soil profiles on steep rocky sites might cause local drought conditions on sites with Eastern and Southern exposure (Panayotov & Yurukov 2007b).

Cores were collected with increment borer at breast height (1.3 m) from 25 to 27 dominant trees that were not affected by avalanches or rock-fall. Tree ring widths were measured in the dendrochronology laboratory at the University of Forestry in Sofia following standard procedures. Rings with specific anatomic features (e.g. “early and latewood frost rings”, “light rings”, “kallus formation”, “rings with reaction wood”) were recorded, photographed and encoded with numbers to facilitate statistical analysis. Obtained tree-ring width series were crossdated with the use of visual clues (Stokes & Smiley 1968) and the computer program COFECHA (Holmes 1983). Then the data was standardized with the software package ARSTAN (Cook 1985) using modified exponential and linear functions. The final chronologies were composed by calculating bi-weighted robust means of annual ring widths. This, as well as the calculation of standard descriptive parameters was performed with the ARTSAN software.

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We also used a *Pinus heldreichii* chronology from treeline location in the Olympus mountains in Greece (Schweingruber 1981) in order to calibrate the reliability of our chronology. We used a portion of it with a replication of more than 4 series. The length is 372 years (AD 1609-1981), the maximum number of series – 30.

The *Pinus peuce* chronology was visually compared with a previously published one (Vakarelov et al. 2001) due to un-availability of the original data series. The comparison reveals general synchronous variability, which is expected having in mind the proximity of locations (Panayotov & Yurukov 2007a).

The analysis of the climate-growth relationship was performed with DENDROCLIM2002 software using average monthly temperatures and precipitation sums for months from June of the year prior to growth to September of the current year. The software uses 1000 bootstrapped samples to compute response and correlation coefficients, and to test their significance at the 0.05 level. Median correlation and response coefficients are deemed significant if they exceed, in absolute value, half the difference between the 97.5-th quantile and the 2.5-th quantile of the 1000 estimates (Biondi & Waikul 2004).

Results and Discussion

The *Pinus peuce* chronology consists of cores from 27 trees and has a length of 305 years (AD 1700-2004). Longer series were truncated at that year to avoid low replication. The oldest found *Pinus peuce* tree had 614 tree rings. The mean tree ring width is 0.114 mm, the mean standard deviation of tree ring width is 0.040, the autocorrelation (1-st) is 0.771 and the mean sensitivity is 0.175 (for more details about the *Pinus peuce* chronology, see Panayotov & Yurukov 2007a).

The *Pinus heldreichii* chronology is based on the dataset of Panayotov & Yurukov (2007b) but has been additionally improved by adding samples. It consists of cores from 25 trees and is with length of 655 years (AD 1350-2004). The oldest found *Pinus heldreichii* tree had 762 tree rings. The mean tree ring width is 0.091 mm, the mean standard deviation of tree ring width is 0.037, the autocorrelation (1-st) is 0.772 and the mean sensitivity is 0.195. The minimum number of used series is 4.

The comparison between our *Pinus heldreichii* chronology and the one from Greece reveals high correlation - 0.508 ($p<0.001$). Pointer years coincide, which is a sign of chronology reliability . This also reveals similar climate influence on the trees at both sites. Having in mind the closeness of the mountain ranges and their presence in the same climate region, this is expected.

The correlation analysis between the *Pinus peuce* chronology (Fig.2.) and the climate data from Bansko shows statistically significant positive influence on growth by temperatures from beginning and end of previous vegetation season (June and October) and the respective summer (June) (Fig. 3.). Influence of high precipitation during the growth period is negative. This is most probably due to the negative relationship between precipitation and temperature values (Correlation of average June-August monthly temperatures to precipitation sums is -0.52, $p\leq0.05$), especially in years with extremely high precipitation in summer, such as 1940, 1947, 1949, 1959, 1976, 1983, 1989, 1995 and 2002.

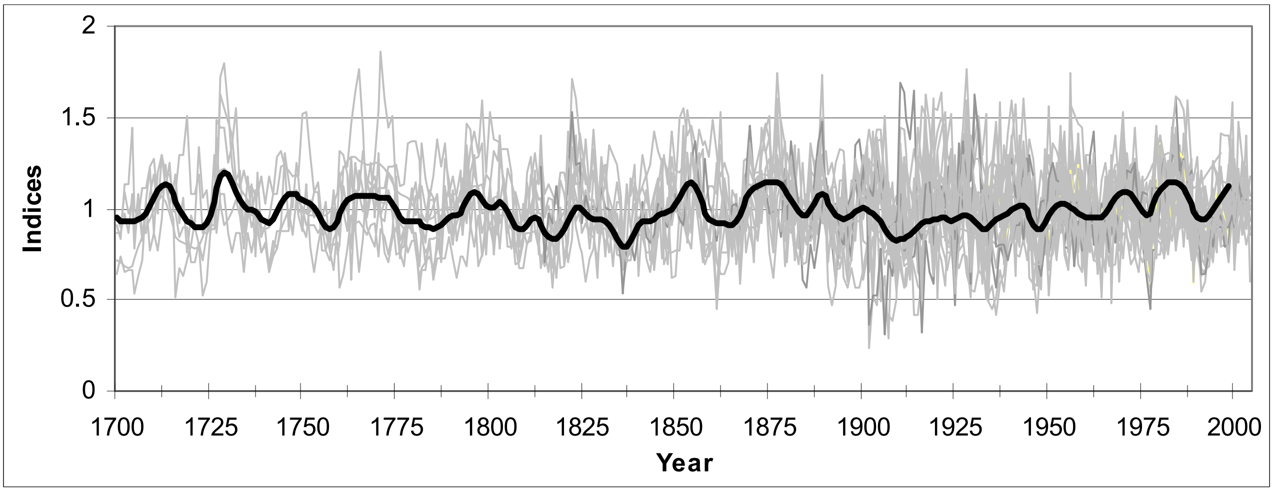
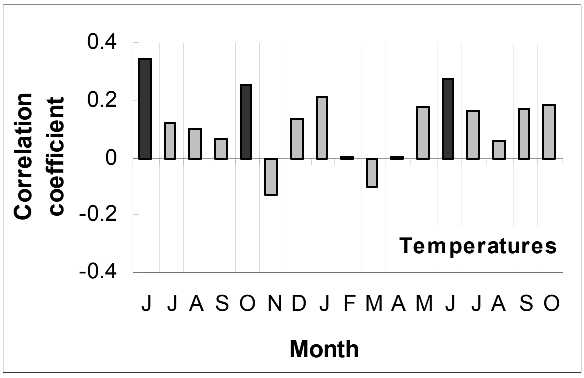


Figure 2: Tree ring chronology from Pinus peuce Griseb., Pirin Mts., Bulgaria. The chronology is presented as 13-year low-passed series.



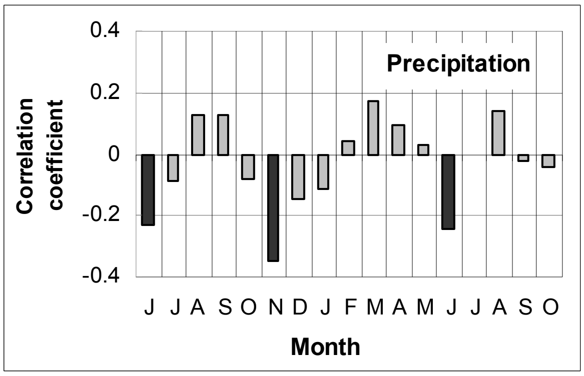


Figure 3: Correlation coefficients for the tree growth – climate relationship of the Pinus peuce chronology. Statistically significant values are marked with black rectangles.

The correlation analysis between the *Pinus heldreichii* chronology (Fig. 4.) and the climate data shows statistically significant negative influence on growth by temperatures of previous and the respective summer (Fig. 5.). Influence of precipitation in the typical summer months is positive.

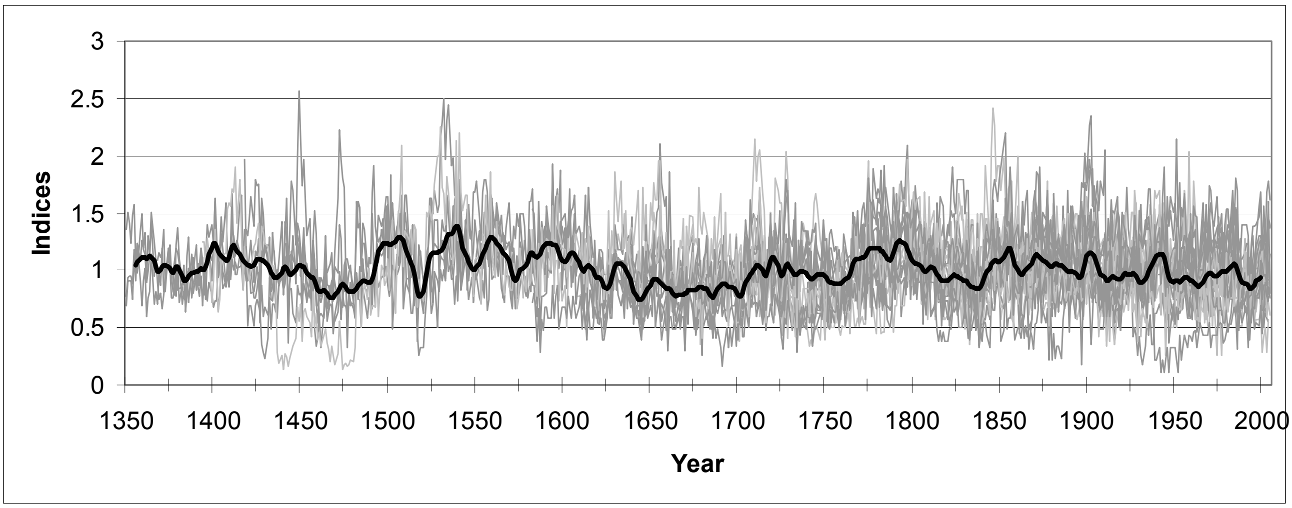


Figure 4: Tree ring chronology from Pinus heldreichii Christ, Pirin Mts., Bulgaria. The chronology is presented as 13-year low-passed series.

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The results for the climate-growth relationships demonstrate that although the trees of the two species grow at the treeline in the same valley, they have different reaction to summer precipitation and temperatures. The *Pinus peuce* have the expected reaction for high-mountain site, e.g. limiting influence of summer temperature regime (Fritts 1976). The *Pinus heldreichii* trees react negatively to situations with high temperatures and low precipitation. This demonstrates that even at treeline, the trees are very sensitive to local drought conditions. This is explainable by the extremely steep rocky site, on which the trees are growing and the consequent quick drying of the shallow soil profile in precipitation-free periods. Yet, a climate-growth correlation analysis alone might be misleading in the understanding of tree's reaction to specific climate conditions. Therefore we have also chosen to review the pointer years in both chronologies and to compare them to the climate records for verification. Such analysis reveals that both species have years in which they have reacted in a similar way (e.g. 2000, 1999, 1986, 1970, 1963, 1956, 1946-47, 1938, 1934 in the past century), and years in which they have opposite reactions (e.g. 1993, 1992, 1989, 1987, 1978, 1977, 1976, 1973, 1971, 1958, 1957).

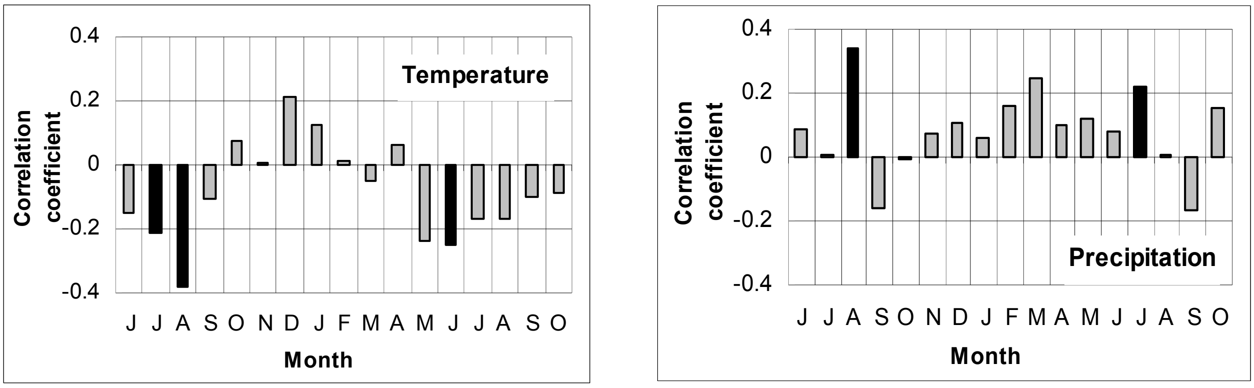

Figure 5: Correlation coefficients for the tree growth – climate relationship of the Pinus heldreichii. Statistically significant values are marked with black rectangles.

The review of the years, in which the trees have reacted in a similar way, reveals two general situations. The first, in which the formed tree rings were wider than the average, the summers were with high or normal temperatures and in the same time with normal precipitation (e.g. 1999, 1986, 1970, 1956). In some of these cases winter and early-spring precipitation was higher than the average. Most of the years, in which both species formed narrow tree rings, were years with very dry July or August (e.g. 2000, 1963, 1938), generally very dry years (e.g. 1946-1947) or years with very cold preceding summer (1934). This demonstrates, that *Pinus peuce* trees although growing at treeline on shady sites also might experience growth problems in years with lack of summer moisture (Panayotov & Yurukov 2007a). As discussed the *Pinus heldreichii* reaction in such years is explainable by the micro-site soil conditions.

The review of the years with opposite reactions reveals two major situations. The first is when *Pinus peuce* trees form narrow tree rings while *Pinus heldreichii* form wide or close to the average. These years are characterized with cold vegetation period, often with higher than normal precipitation (e.g. 1989, 1976, 1971) or with unusually cold previous summer or autumn (e.g. 1992, 1977, 1973, 1971). In some of these years the trees have also formed “light rings”. They are more typical for *Pinus peuce* and are clear markers for unusually cold summers like 1933 and especially 1976 (Panayotov and Yurukov, 2007a). Such reaction is typical for trees, which grow at high altitudes or latitudes (Filion et al. 1986; Gindl 1999; Hantemirov et al. 2004).

Years, in which the *Pinus heldreichii* trees have formed narrow tree rings while the *Pinus peuce* have formed wide or close to the average tree rings are characterized by unusually dry beginning of the summer – June or May (e.g. 1993, 1987, 1978, 1958). This is an additional indication of the importance of local micro-site conditions for the *P. heldreichii* trees. While a drought in July and

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August could affect both species, since the moisture reserves in the soils have been exhausted, a precipitation-free period in June could affect only trees that grow on very thin soils with low water-holding capacity and with limited capacity to store the winter moisture reserves for continuous periods. Such reaction is also explainable by the regional climate in Pirin Mountains range. For the Mediterranean climate it is typical to have high precipitation in autumn and winter and low during summer. Since the mountains serve as a climate barrier for the Mediterranean air masses, they are strongly affected by this regime. In terms of climate-growth analysis, this is of high importance since it demonstrates that climate data from other nearby stations, which are less influenced by the Mediterranean climate, should be used very carefully.

Conclusions

The presented results show that *Pinus peuce* and *Pinus heldreichii* trees from Pirin Mountains demonstrate mixed climate signals and are influenced by both low summer temperatures and periods with low precipitation. This means that direct climate reconstructions should be performed only after considering the chance to have pointer years, that might be due to an opposite climate situation. At the same time gives the chance to obtain precise data for past periods with both, extremely dry or cold summers. Such data is scarce for the region, but of great importance. We consider that a proxy record like this can be obtained by simultaneous analysis of chronologies of both species. Therefore it is necessary to improve the existing datasets by adding new series, which is about to be done.

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