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Exploring the potential of *Pinus heldreichii* CHRIST for long-term climate reconstruction in Albania

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Introduction

Recent global warming and its potential impact on the hydrological cycle and subsequent ecological implications strengthens the need to quantify the degree of past natural climate variability. This demand becomes even more critical particularly for drought sensitive though, densely highly populated regions with intense agricultural background, such as most of the Mediterranean basin. Although significant progress has been made in assessing past climate variations over Europe, most long-term high-resolution reconstructions are restricted to temperature variations at high latitudes or altitudes. The Balkan Peninsula plays a key role as climatic transition zone between the west and eastern Mediterranean and also between the Mediterranean and Central European synoptics (Griffiths et al. 2004, Xoplaki et al. 2003, Xoplaki et al. 2004, Nicault et al. 2008, Qiriazi & Sala 2000). It is, however, still in an early stage of development from a dendroclimatological perspective (Vakarelov et al. 2001, Panayotov et al. 2009 a, b, Büntgen et al. 2007, Popa & Kern 2009).

Albania appears as a pure white spot in terms of existing tree-ring studies but provides large areas of *Pinus heldreichii* CHRIST forests, an endemic, long-living high-elevation species on the Balkan Peninsula and southern Italy.

Here we present new millennium-long tree-ring width (TRW) and maximum latewood density (MXD) records of various *Pinus heldreichii* sites across Albania. We explore local- to regional-scale signal strength of the different chronologies, and evaluate parameter-specific climate sensitivity with particular emphasize on potential age-related changes in climate response. Our results are discussed in the light of potential long-term climate reconstruction.

Data and methods

Three ecologically different high-elevation sites along a north-south gradient in Thethi (AT), Lura (AL) and the Cuka Partisan in the Tomorri massive (AP) were sampled (Fig. 1, Tab. 1). The most northern region Thethi is located in the Dinaric Mountains on limestone bedrock. Three sites were sampled on a south/east exposed slope at different altitudes (AT1 1700 m, AT2 1900 and AT 3 1800-1900 m a.s.l). In the adjacent Albanian Mountains the Lura site (National Park since 1966) is characterized by basic metamorphic bedrock. Samples at AL1 were taken around a small lake in 1800 m a.s.l., while AL2 is situated on a steep south/west exposed slope close to the local tree line in 2000 m a.s.l. The Cuka Partisan is the most southern region where samples were taken in 1800-2000 m a.s.l. in stands on Leptic regosols above limestone bedrock. AP1 and AP2 differ in their ecological conditions in the sense that AP2 is located on a very shallow, dry steep rocky slope. Particularly, at Thethi and Lura also dry dead wood remains display an important source to extend living chronologies back into medieval times.

Two cores per tree (living and dead wood) were sampled with a 5 mm diameter increment borer. Furthermore, samples from dead wood were taken as stem disks. TRW was measured by separating early and late wood width. MXD was measured for a subset of 7 cores (4 series from AT, 3 series from AL), which cover the period 1796-2006.

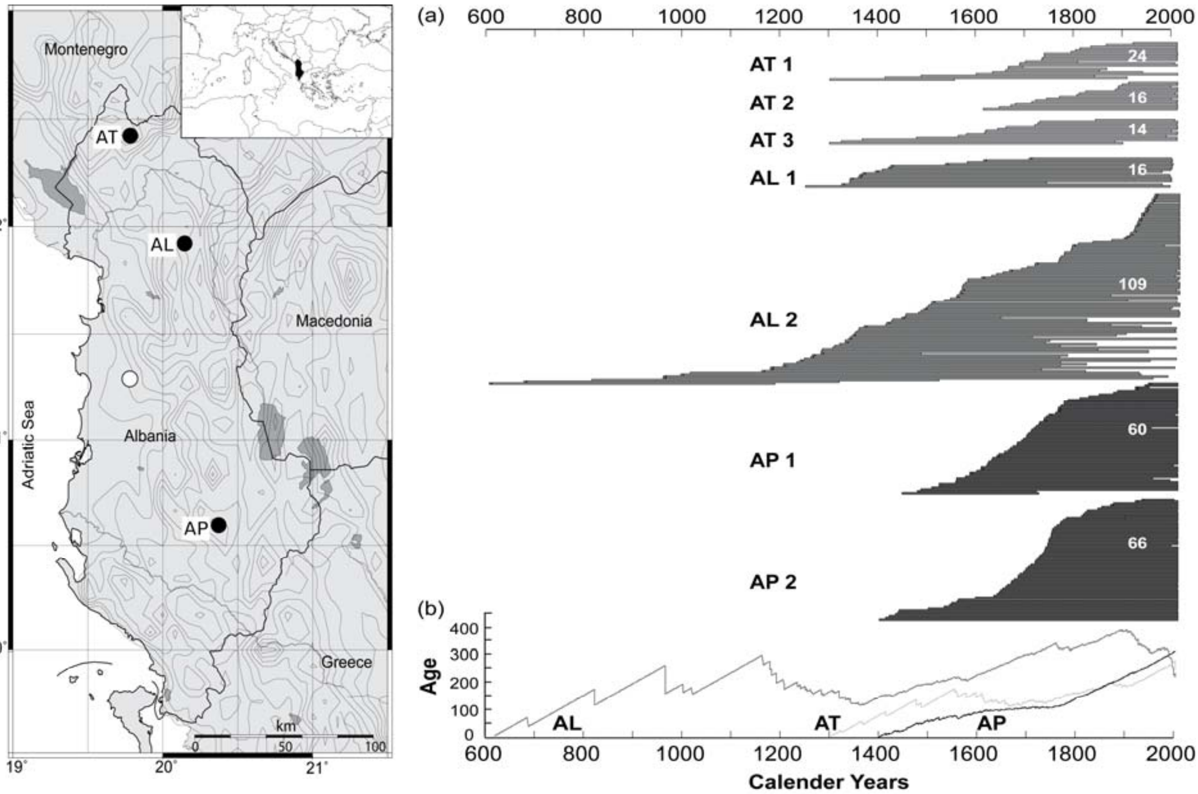

Figure 1: a) Location of the sampling sites (black circles) and instrumental station data of Tirana (white circle); b) Replication and mean cambial age of the three sampling sites, with each bar representing one individual series.

Maximum and mean segment lengths (MSL) of the series are 638 and 277 years for AT, and 604 and 308 years for AP (Tab. 1).

The highest replication is 99 trees and 124 radii (AL), including dead and living wood (Fig. 2). This site also provides the oldest material (mean segment length 397 years), with one dead individual counting even 1017 tree rings.

For all samples were the pith couldn't be reached because of sizable tree diameter, the number of missing innermost rings (pith offset, POE) was estimated. This procedure allows a more accurate application of regional curve standardization (RCS, Esper et al. 2003). The average POE ranges from 41 years at AP to 118 years at AT (Tab. 1).

According to standard procedures, tree-ring width (TRW), but also early (EWW) and late wood width (LWW) measurements were performed. Resulting series were cross-dated and any dating errors corrected before removing non-climatic, tree-age related growth trends (Fritts 1976). Based on RCS detrending we developed 7 site chronologies, 3 regional chronologies (AT, AL, AP) and one master chronology (ALB). Moreover, three chronologies based on different age classes (<300 years, 300-500 years and >500 years) were developed using the full data set to test if climate signals are age dependent. All resulting records capture inter-annual to centennial scale information and were subsequently compared with regional instrumental records.

Table 1: Main characteristics of the site and regional chronologies combined in the Albania data set. Listing of the location, number of trees and radii, covered time span, mean segment length and mean interseries correlations of the raw and RCS-detrended Rbar-values.

Code	Elev. (m a.s.l.)	Trees (n) TRW/ *LWW*	Radii (n) TRW/ *LWW*	Period (truncation > 5 series)	MSL	Rbar (TRW)	Rbar (LWW)	mean Rbar -raw- (TRW)	mean Rbar (TRW)	mean Rbar (LWW)
AT	**1700 - 1900**	**41/ -**	**54/ -**	**1303 (1479) - 2007**	**277**	**0.53**	-	0.17	0.16	-
AT 1	1700	18/ -	24/ -	1306 (1660) - 2007 (2006)	236	0.453	-	0.12	0.15	-
AT 2	1900	12/ -	16/ -	1614 (1720) - 2007	228	0.558	-	0.25	0.22	-
AT 3	1800 - 1900	11/ -	14/ -	1303 (1580) - 2007 (2006)	404	0.578	-	0.27	0.18	-
AL	**1800 - 2000**	**99/ *92***	**124/ *113***	**617 (1003) - 2008**	**397**	**0.523**	**0.284**	0.22	0.14	0.11
AL 1	1800	16/ *16*	16/ *16*	1257 (1374) - 1997	546	0.498	0.157	0.12	0.27	0.05
AL 2	2000	82/ *76*	108/ *97*	617 (1003) - 2008	375	0.548	0.32	0.21	0.17	0.14
AP	**1800 - 2000**	**79/ *79***	**126/ *126***	**1405 (1445) - 2008**	**308**	**0.564**	**0.342**	0.24	0.21	0.16
AP 1	1800 - 2000	39/ *39*	60/ *60*	1451 (1526) - 2008	302	0.567	0.339	0.19	0.16	0.13
AP 2	1800 - 2000	40/ *40*	66/ *66*	1405 (1445) - 2008	313	0.584	0.358	0.31	0.26	0.18

For analysing the growth/climate response, instrumental temperature (1951-1981) and precipitation (1951-1990) data of Tirana (89 m a.s.l., 41° 18'N, 19° 48'E), were used covering the period 1951-1981 for temperature and 1951-1990 for precipitation. Due to the shortness of the local measurements, longer instrumental station data from Thessaloniki in Greece (115 m a.s.l., 40° 39'N, 22° 58'E) were applied. Mean annual temperatures between Tirana and Thessaloniki correlate by 0.75 ($p<0.01$) for the common period of 1951-1981, precipitation data, however, do not appropriately represent local conditions ($r=0.38$, $p<0.05$). Additional calibration tests using meteorological grid data of 0.5° resolution (CRU TS 2.1; Mitchell & Jones 2005) did not provide convincing results.

Results

Site chronologies

The strength of the common signal within the local and regional data sets is indicated by the mean inter-series correlation (Rbar) (Tab. 1) and the „Expressed Population Signal" (EPS) (Fig. 2). Values reaching the threshold of 0.85 indicate that the chronology appropriately represents the population growth at the site (Wigley et al. 1984). Robust EPS and Rbar statistics reach back to 1585 AD at AT, to 1295 at AL, and to 1535 at AP. The LWW records are generally more heterogeneous, but contain a robust common signal as well at AL from 1370 AD and at AP from 1635 AD on.

RCS-detrended site chronologies (TRW) at Thethi correlate between AT1 and AT2 with r=0.45, between AT2 and AT3 with r=0.50 and between AT1 and AT3 with r=0.41, at Lura between AL1 and AL2 with r=0.41 and at Cuka Partisan between AP1 and AP2 with r=0.58 (all: $p<0.01$; common period 1405-1997). The correlations between regional chronologies vary but in all cases are highly significant ($p<0.01$). Highest relationships are found between regions close to each other, with AT-AL r=0.61, AL-AP r=0.67 and between AT and AP r=0.38 (common period 1405-2007), mirroring nicely the north-south gradient. Interestingly the Thethi region shows a different long-term behaviour in the late 20th century with a decreasing instead of an increasing trend. Although RCS-detrended LWW chronologies weakly correlate between sites, regional chronologies of AP and AL are highly correlated with r=0.65 (p<0.01; common period 1405-1997).

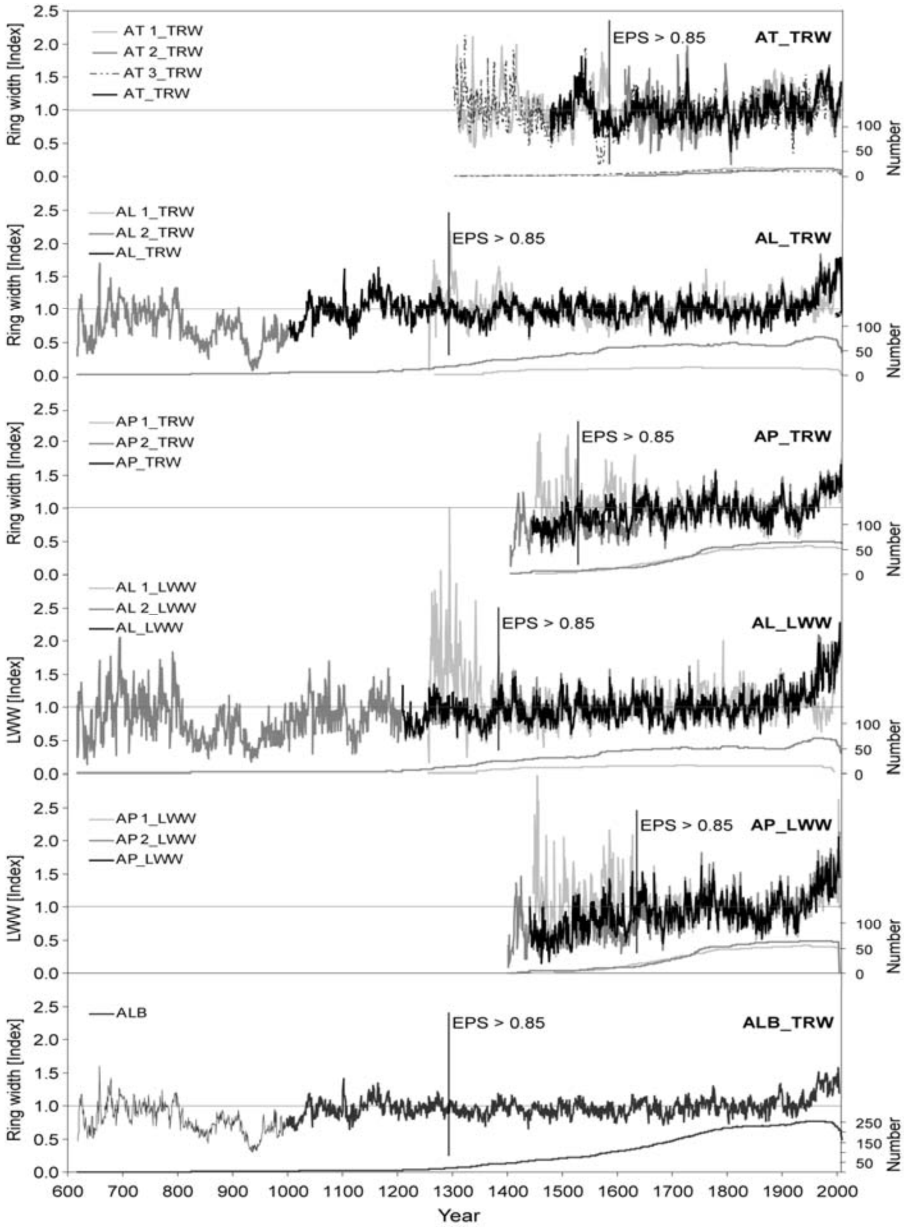

Figure 2: RCS-detrended TRW and LWW chronologies separated by sites after standardisation over their full lengths. At the bottom all regional TRW-chronologies combined to a master chronology. In black the regional chronologies and the master chronology (ALB) after truncation <5 series. Vertical lines indicate the dates where the EPS is robust above the 0.85 threshold.

Since both chronologies at Lura (AL1 and AL2) are composed of different age classes with AL2 containing many young and AL1 only old trees, it becomes obvious, that the influence of younger trees plays an important role in preserving longer-term trends (Fig. 2). We investigated this finding by splitting the complete data set (ALB, Albania) into age classes of young (<300 years), middle (300-500 years) and old (>500 years) tree rings. At the same time, we ensured evenly replicated subsets. Resulting age classes reflect different growth trends: the young trees grow faster by ~2 mm than the middle and old trees with just 1.5 mm (Fig. 3a).
Deviations in long-term trends of RCS-detrended age-class chronologies until 1850 are obviously caused by declining replication of young trees in this period (Fig. 3b). After 1950 the <500 age

class remains on a persistent growth level while the young age class shows a slightly increasing trend. Decadal scale patterns of all age classes, however, are rather similar, particularly between 1900 and 1960.

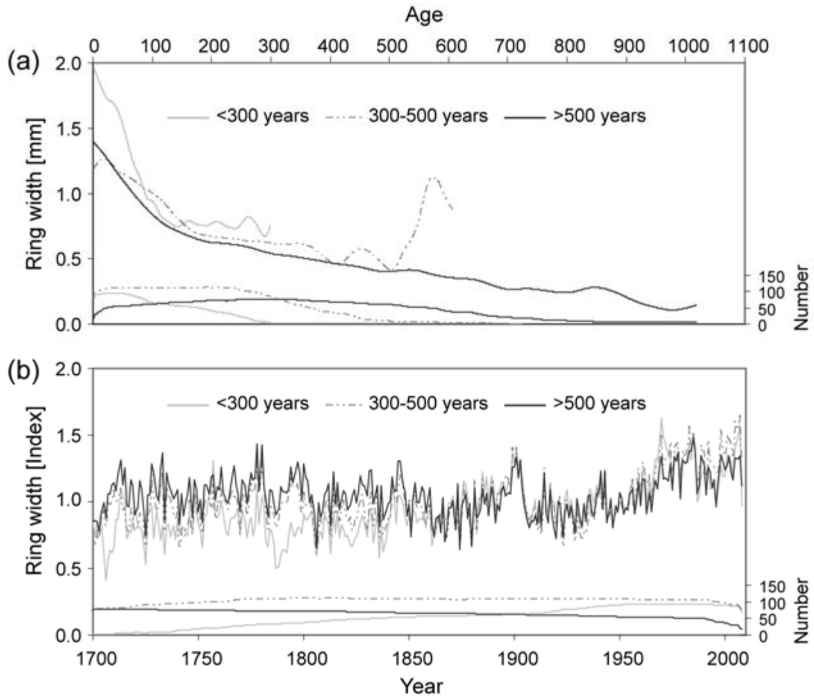

Figure 3: (a) Mean growth trend in the three age classes (b) RCS-detrended age-class chronologies for the last 300 years. At the bottom of the panels the sample replication is shown.

Climate response

Correlations of regional (AT, AL and AP), age-class and MXD chronologies against local instrumental temperature and precipitation data of Tirana (1951-1981 and 1951-1990) were computed using a 24-month window from previous year January to current year December, along with various seasonal means and sums, respectively (Fig. 4). Besides positive correlations with temperatures and negative correlations with precipitation of previous May, summer (June/July) temperatures of the current as well as the previous year correlate negatively to TRW of high mountain pine at our sites (Fig. 5, left). The negative influence of high temperatures on tree growth is interpreted as indirect drought signal. AT reacts most strongly to previous and current July, a signal that is slightly weaker recorded in the latewood width especially of the southern region AP, and also in the different age classes (Fig. 5, right). Taking also positive (although weak) precipitation correlations into account, it seems, however, that younger tree-rings (<300 years) react more sensitive to drought conditions particularly in the driest months July and August. Consequently, the climate information contained could be related to climate-signal age-effects, as reported earlier (Esper et al. 2008). In contrast MXD yields, with care of the very low replication, high positive correlations to summer, particularly August temperatures ($p<0.05$) and no significant correlation to precipitation. This finding is promising but needs to be confirmed by more proxy and better target data.

It has to be noted, however, that all relationships are represented by a short 31-year common proxy/target period only. When replacing local temperature data of rather limited length with century-long instrumental measurements of Thessaloniki for the same period, most of the significant correlations stay robust (not shown). Extending the time window to the full period (1900-2008), however, refutes any significant relationships except for Thethi, where negative correlations to summer temperature remain and only decrease from $p<0.01$ to $p<0.05$. Figure 5 shows that the correlation between TRW (<300-year age class) and summer temperatures is associated with a temperature decrease to coolest and also moist conditions (not shown) of the 20th century. This increase of the negative influence of summer temperatures is also confirmed by moving correlation. The positive MXD-temperature relationship seems to be mainly related to the high frequency, is robust until the 80ths and brakes down afterwards.

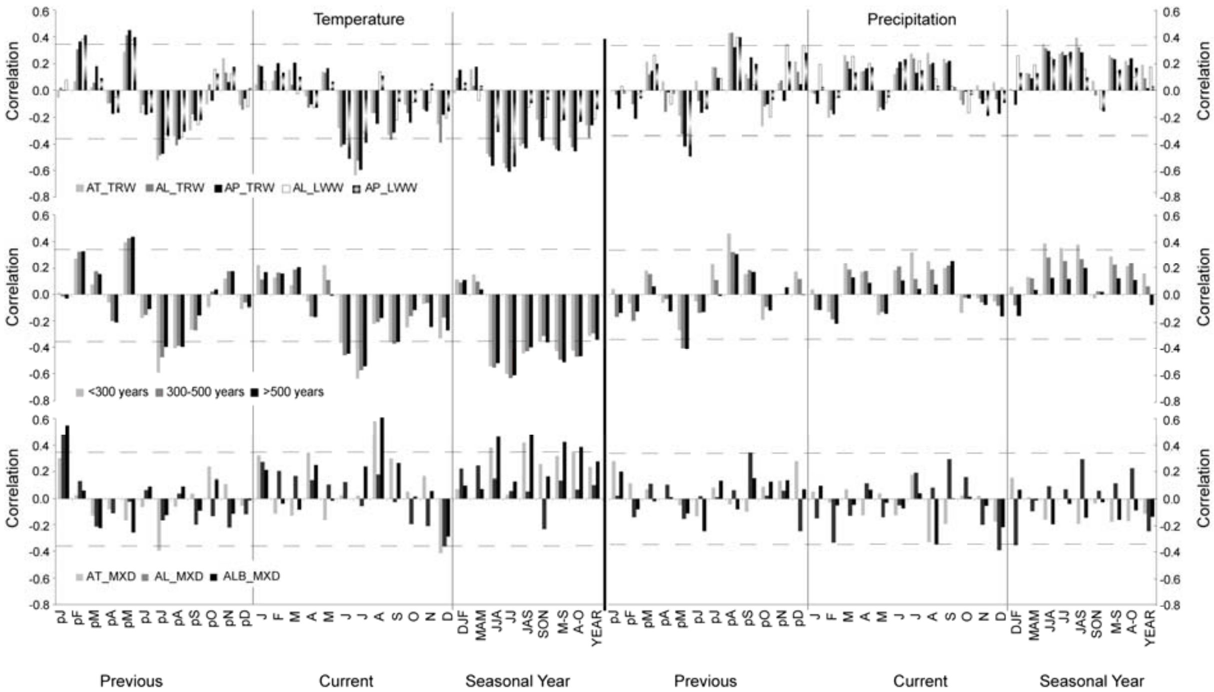

Figure 4: Growth/climate response of TRW, LWW, age classes and MXD using temperature (1951-1981) and precipitation data (1951-1990) of Tirana for the period 1951-1981. Horizontal dashed lines represent the 95% significance level.

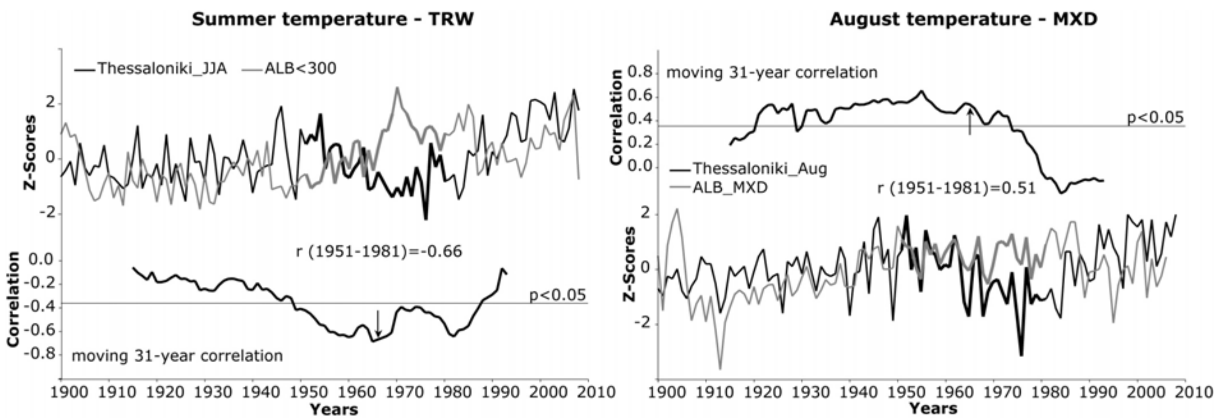

Figure 5: Correlation of TRW and MXD with instrumental station data of Thessaloniki (Greece) and moving correlations in 31-year time windows; Left: <300 years age-class TRW chronology and JJA temperatures, right: initial MXD chronology and August temperatures. Arrows indicate the correlation obtained with instrumental data of Tirana.

Discussion and Conclusions

We developed a 1391-year long tree-ring width chronology including living and dead *Pinus heldreichii* CHRIST trees from Albania (617-2008 AD). Robust Rbar and EPS statistics are recorded back to 1250 AD. Regional records were separately correlated with the instrumental station data from Tirana and Thessaloniki. Climate correlation tests of RCS-detrended TRW and LWW records

with local data show a negative response to June-July mean temperatures (common period 1951-1981) and a positive, but lower response to the precipitation amount at the same time.
The high common signal observed both within and between Albanian regions and similarities of our Albanian master chronology with other high elevation *Pinus heldreichii* chronologies from Bulgaria (Panayotov et al. 2009), Greece (Kuniholm & Striker 1987) and Italy (Serre-Bachet 1985) indicates that this species captures a common signal over a broader area.
Climate growth relationships were performed with data partly far away from our sampling sites. Negative correlations to temperature have to be interpreted as indirect indicator for drought sensitivity. Low correlations with local precipitation data may indicate that these records still do not appropriately represent local site conditions and, hence, need to be interpreted with care. Panayotov et al. (2009) also observed a similar relationship of the radial growth pattern of *Pinus heldreichii* in the Pirin Mountains (Bulgaria) to high temperatures and low precipitation in summer under similar site conditions on soils with a low storage capacity of water during dry months.
Analyses of various age classes indicate that younger trees contain more distinct variations than old tree-rings (>500 years). Taking also positive (although weak) precipitation correlations into account, it seems that younger trees (<300 years), react more sensitive to drought conditions particularly in the driest months July and August maybe due to shallow root systems. Our first tests with drought indices such as PDSI (van der Schrier et al. 2006), however, did not yield convincing results. Additionally, it needs to be considered that despite sampling was performed at the highest forested elevations the thermal tree line in the study area would be about 500m higher. In combination with an extended vegetation period, this results in less defined growth controls (Körner 1998).
In conclusion, tree ring chronologies of Albanian high elevation *Pinus heldreichii* contain a strong common signal and potential to cover at least the last millennium, although the climatic signal is still too weak for robust reconstruction. We hypothesize that (a) the instrumental data currently used are not yet appropriate enough to clearly identify the signal recorded and that (b) our sites might not be “extreme” enough to be continuously controlled by one meteorological variable only. MXD data seems to be a useful complementary parameter for “pure” temperature information, as reported for other relatively dry western Mediterranean sites (Büntgen et al. 2008). To substantiate the strength of the signal, however, more extensive measurements of MXD are required to raise the replication.
Future efforts will focus on (i) additional material to increase sample replication before 1250 AD, (ii) dead wood, historical timbers and sacral icons, (iii) low-elevation *Pinus nigra* sites, (iv) longer and better homogenized instrumental data (v) stable isotope measurements to enhance the drought signal (Treydte et al. 2007) and (vi) local- to regional-scale drought reconstructions

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