Over two millennia long ring-width chronology of Himalayan pencil cedar from Western Himalaya, India

Climate change has been the major driver in the rise and fall of important civilizations in human history. Even in modern times, frequent occurrence of extreme weather conditions continues to cause serious havoc to socio-economic activities in our country. Weather records of the past century show that the 1918 drought, when ~69% of the geographical area of the country experienced deficient monsoon rains, caused a devastating impact on the society[1]. Understanding the recurrence behaviour of such extreme events is required to adopt appropriate mitigation measures. However, the weather data of the last century do not provide a sufficient time window to understand natural variability of such extreme events in long-term perspective. High-resolution proxy climate records such as annual growth ring sequences in trees, which could be precisely dated to seasonal/annual level, offer a unique opportunity to supplement weather data back to several centuries and millennia[2–5].

In India, several growth ring-forming tree species in tropical and temperate forests are known to grow over thousand years[6]. But due to the extensive use of forest resources over centuries, such old trees are difficult to find in areas easily accessible to humans. However, in the Himalayan region some old trees could still be found on steep rocky slopes or interior locations where harvesting is difficult. Some of the conifer species, i.e. Himalayan cedar (*Cedrus deodara* (Roxb.) G. Don), neoza pine (*Pinus gerardiana* Wall. ex. Lamb) and Himalayan pencil cedar (*Juniperus polycarpos* C. Koch), which grow in harsh ecological conditions in the Western Himalaya are found to be very old, usually exceeding 1000 years[2–4,7]. Amongst these, the Himalayan pencil cedar, which extends to extreme arid regions in the high-elevation Western Himalaya, is found to be the longest living tree species in India[7]. Such old trees usually found growing in harsh ecological conditions could be recognized by their stunted growth, crown die-back and thick branches (Figure 1). Yadav *et al*.[7] first reported ~1600 years (AD 420–2003) precisely dated ring-width chronology of Himalayan pencil cedar from Lahaul-Spiti region in Himachal Pradesh. Seeing the potential of this species in the development of long chronologies, extensive surveys were made again in 2007 and 2008 to collect tree core samples from old trees. The chronology presented here, based on the tree core samples from these collections, extends the earlier chronology further back by 438 years.

The increment core samples of Himalayan pencil cedar trees growing over cold arid regions in Lahaul-Spiti, first collected in 2004, were supplemented by additional collection of tree core samples in 2007 and 2008 from different sites (Figure 2). The forests selected for sampling constitute open stands from high-elevation sites located between 3200 and 3600 m amsl in Lahaul-Spiti. Although the tree-ring sampling sites are scattered over a wide area, their ecological settings are homogenous. The openness of the forest stands over all the sites ensures that tree-ring series are free from the stand dynamics effects and have maximum chance for retaining climate signal. The air-dried core samples fixed on wooden frames with the transverse (cross-sectional) surface exposed on top were polished with progressively fine abrasive paper and growth rings analysed under stereozoom binocular microscope. In all, 40 core samples from 30 trees having >1000 rings were selected to prepare the ring-width chronology. The tree-ring sequences were cross-dated by skeleton plotting[8] and ring-widths measured to 0.01 mm accuracy using the LINTAB measuring system (Rinntech, Heidelberg, Germany). The dating of growth-ring sequences was rechecked using the dating quality control programs COFECHA[9] and TSAP[10]. The COFECHA analysis revealed a mean correlation of 0.56 for all the 40 samples with the master series endorsing the quality of dating of growth-ring sequences. For chronology preparation, first, a power transformation was applied to all tree-ring measurements to stabilize the variance in the heteroscedastic tree-ring width measurement series[11]. The power-transformed measurement series were then standardized using cubic smoothing spline with a 50% frequency response cut-off width equal to two-thirds of the individual series length and chronology calculated as a biweight robust mean of the differences between the raw measurement data and the fitted splines using the program ARSTAN[12]. The standard version of the chronology spanning over 2023 years (16 BC–AD 2006) along with the number of samples used is shown in Figure 3. The threshold value of expressed population signal taken as a measure of population signal in the chronology[13] reached a value of 0.83 and above back to AD 600 with the replication of 10 core samples.

The sampling area lying in the rain-shadow zone of Pir Panjal range receives little or no rain during the summer monsoon season (June–September). The mean annual precipitation in the area is ~600 mm, majority of which falls during winter and spring largely due to westerly disturbances. The present ring-width chronology could not be calibrated with climate data due to lack of weather records from any station close to the sampling locations. However, for preliminary climate/growth relationship, the climate data of Srinagar (34°08′N and 74°48′E, 1587 m amsl; around 230 km from tree-ring sites) located in a similar climatic zone comparable to the sampling area were used. The relationship between the ring-width chronology, monthly precipitation and temperature of Srinagar using multiple regression analysis[14] revealed similar results as reported earlier[5,7]. Mean summer (June–August) temperature showed negative relationship with the chronology ($r = -0.30$,

Figure 1. Over 1000-year-old tree of Himalyan pencil cedar growing near Udaipur, Lahaul-Spiti, Himachal Pradesh. Stunted growth, crown die-back and thick branches of the tree reflect its old age.

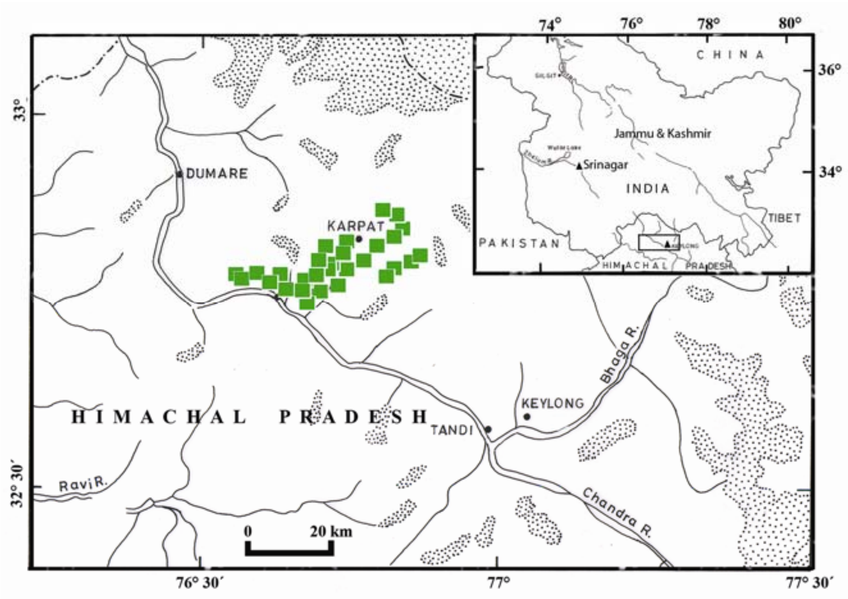

Figure 2. Location of tree-ring sampling sites (filled rectangles). (Inset) Location of Srinagar meteorological station (filled triangle) used in the study.

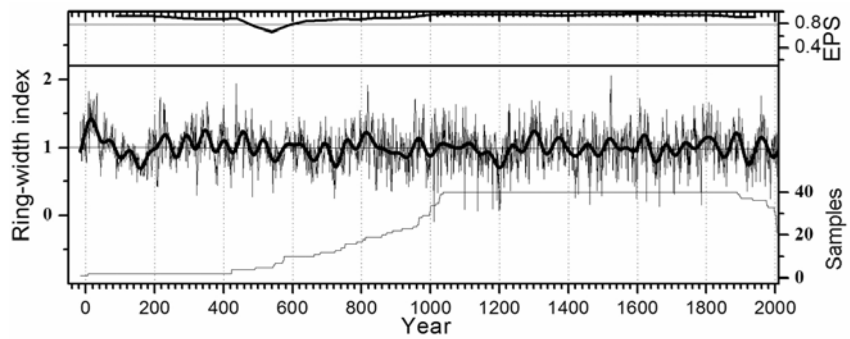

Figure 3. Standard ring-width chronology (16 BC–AD 2006) with the number of samples used in chronology preparation. The thick line superimposed over the chronology is 50 year low pass filter. (Upper panel) Expressed population signal (EPS) calculated over a 50-year period with 25 years overlap.

1951–2004, $P = 0.0275$), indicating that growth of Himalayan pencil cedar trees is favoured during cool summers. The relationship with monthly precipitation except for the month of May was weak, which could indicate that due to high spatial variability in precipitation under dominant orographic forcing Srinagar records do not exactly reflect the precipitation over the study area.

The present Himalayan pencil cedar ring-width chronology spanning over 2023 years (16 BC–AD 2006) presented here and its significant relationship with monthly climate variables open new vistas in dendroclimatic research in India. The availability of old living trees and relic wood materials in such high-elevation, remote locations provides immense potential to extend the present chronology further back by several centuries. Such chronologies offer valuable data to develop long-term climate records useful in understanding the natural variability in climate over the data-scarce cold desert region in the Western Himalaya, India. However, towards the realization of this, we are currently updating the present chronology with the replication of more samples from ecologically homogeneous sites. Higher replication of samples in the mean chronology should help strengthen the common climate forcing signal as highly lobate nature of growth rings in this species smears the climate signal.

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