(*Lakiapollis ovatus*) of Bombacaceae, *Ctenolophona* (*Ctenolophonidites costatus*) of Ctenolophonaceae, *Cryptopolyporites cryptus*, *Polycolpites* spp. and *Polygalacidites* indicates freshwater swampy conditions at the time of deposition. The absence of marine microfossils like dinoflagellate and foraminiferal linings in the lignite indicates deposition in distinctly terrestrial setting. The prevalence of humid tropical climatic conditions and heavy rainfall[21–23] is indicated by the record of high frequency of fungal remains, especially epiphyllous fungi Microthyriaceae from the sediments as well as amber.

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Age of Himalayan cedar outside its natural home in the Himalayas

The Himalayan cedar popularly known as deodar (*Cedrus deodara* (Roxb.) G. Don) is endemic to Hindu Kush, Karakoram and western Himalaya. Natural distribution of this species in the western Himalaya is restricted to areas receiving winter snow and summer monsoon rainfall. With the decreasing amount of winter snowfall from northwest to eastern part of the Himalaya, the deodar gradually disappears in natural forests. In scientific studies, Garhwal is taken as the natural eastern limit of Himalayan cedar in the western Himalaya[1]. But, exceptions to this also exist in the literature as indigenous forests of Himalayan cedar were reported in 1924 in Karnali Valley, West Nepal[2]. However, Bhattacharyya *et al.*[3] while studying tree core samples of Himalayan cedar from Giri Gaon (29°45′N and 82°10′E), Nepal, could establish only 265 years (AD 1714–1978) chronology. Atkinson[4] mentioned that there is no natural grove of Himalayan cedar in Kumaon, and these could have been first planted in temple complexes. According to his estimates[4], numerous plantations of Himalayan cedar around temples in Kumaon aggregate ~800 acres. Though Himalayan cedar is known to grow over thousand years in the western Himalayan region[5], the age of plantation trees in sacred groves around temples in Kumaon is not known. In Hindu mythology Himalayan cedar for its grandeur appearance is treated as sacred and the most preferred tree to be planted in temple complexes. Whether the age of Himalayan cedar plantations is contemporaneous with the construction of temples is not precisely known. Popular belief indicates that Himalayan cedar was first introduced in Jageshwar temple area in Kumaon, where it has almost naturalized with good regeneration. Though these sacred groves of Himalayan cedar in Kumaon region are still patchy, they play a crucial role in maintaining good floral and faunal diversity.

The Jageshwar temple, dedicated to Lord Shiva, was built ~9–13th century AD and plantation of Himalayan cedar trees could have commenced after that. To ascertain the date of plantation of Himalayan cedar around temple complexes, we surveyed and collected increment core samples from old-looking

Himalayan cedar trees in Jageshwar and Gangolihat, Kumaon region in May 2013 (Figure 1). We noticed several gigantic Himalayan cedar trees attaining ~9 m girth around Jageshwar temple complex (Figure 2), the age of which could extend to several centuries. We collected increment cores from trees at breast height of boles (~1.4 m) from directions perpendicular to the slope. Usually two cores were collected from old-looking trees from two opposite sides of the boles. The increment core samples were processed and growth ring sequences dated using standard dendrochronological techniques[6]. Very good coherence in growth pattern of trees from both the sites as revealed in COFECHA[7] (mean $r = 0.62$–0.63) and TSAP[8], and year-to-year similarity in ring-width plots endorse the reliable dating of growth ring sequences. We used established dendrochronological procedures to develop tree-ring chronologies[6]. The ring-width chronologies of Himalayan cedar were prepared using the program ARSTAN[9]. To select the detrending method, ring-width measurement plots of trees from different sites were carefully studied. The ring-width plots of tree samples from both the sites revealed that the growth of Himalayan cedar over the sampling sites is influenced by stand dynamic features such as changing competition due to gap formation. Therefore, to maximize the common signal among the samples, we detrended the ring-width measurement series using 100-yr cubic spline with a 50% frequency response function cutoff[10], except in few cases where 50-yr spline was used. However, prior to detrending the ring-width measurement series were power-transformed to stabilize variance in the heteroscedastic ring-width measurement series[11]. The growth trends were removed from the power-transformed individual measurement series by subtraction, which minimizes the end fitting-type bias compared to the ratios. In order to reduce the influence of outliers, the detrended ring-width measurement series of the respective tree series were averaged to a mean chronology (standard) by computing the biweight robust mean[9]. Another set of chronologies was prepared where low-order autocorrelation from detrended series was removed using autoregressive moving average (ARMA) modelling and the resulting residual series averaged to a mean site chronology by computing the

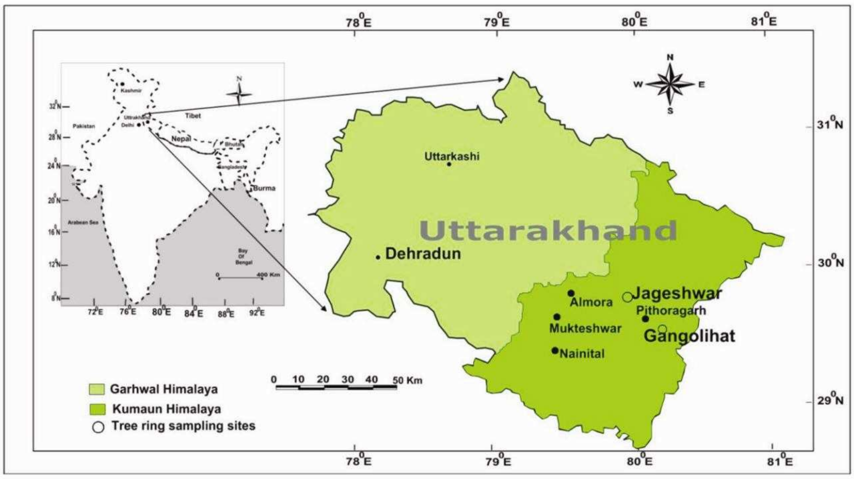

Figure 1. Location of tree-ring sampling sites in Kumaon Himalaya, Uttarakhand.

Figure 2. Jageshwar temple area with Himalayan cedar trees.

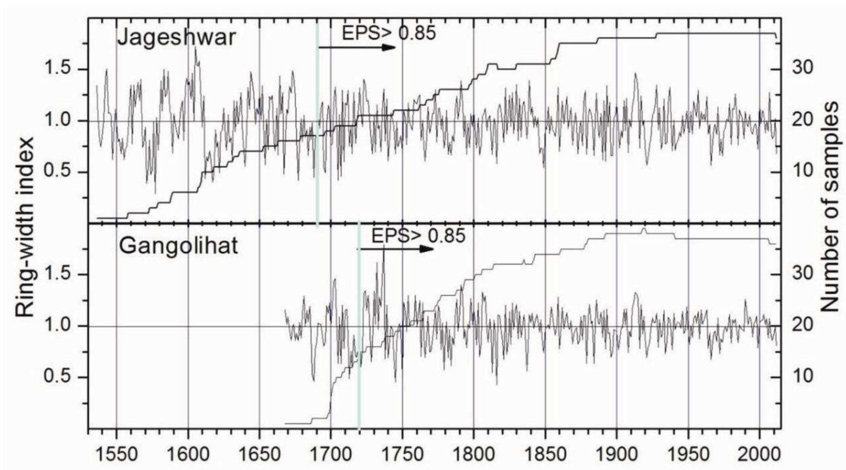

Figure 3. Tree-ring width chronologies of Himalayan cedar from Jageshwar (AD 1536–2012) and Gangolihat (AD 1668–2012) sites with the number of samples used in chronologies preparation.

Table 1. Chronology (standard) statistics of Himalayan cedar from two sites in Kumaon. Details of site locations are shown in Figure 1

Site	Location	Elevation (m)	Core/tree	SY	Chronology with EPS > 0.85	MI	MS	SD	AR1
Gangolihat	29°39′N, 80°01′E	1760	38/27	1668	1720–2012	0.986	0.210	0.192	0.145
Jageshwar	29°38′N, 79°51′E	1851	41/37	1536	1690–2012	0.977	0.257	0.236	0.244

SY, Start year of the chronology; EPS, Expressed population signal; MI, Mean index; MS, Mean sensitivity; SD, Standard deviation; AR1, First-order autocorrelation.

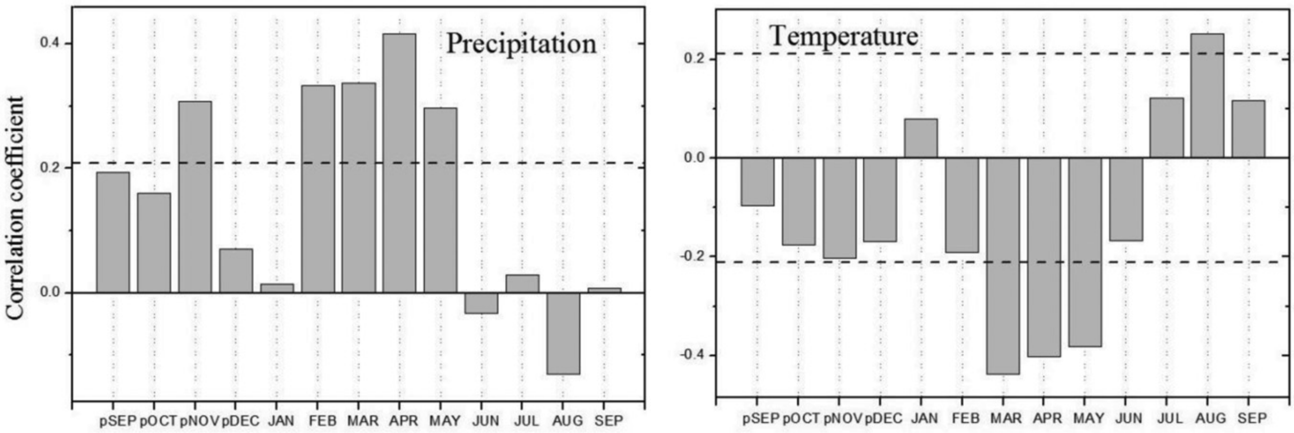

Figure 4. Correlation between the PC#1 of two site chronologies of Himalayan cedar and monthly precipitation as well as monthly mean temperature of Mukteshwar (1901–1991). The dashed line represents 95% confidence level of correlations.

biweight robust mean[9]. The replication of 12–15 tree samples in chronologies from Jageshwar and Gangolihat respectively, was found to be sufficient to achieve expressed population signal (EPS)[12] level of 0.85. The standard version of two site chronologies along with the number of samples used and statistics are shown in Figure 3 and Table 1 respectively. Significant correlation between the above two site chronologies for the common period 1720–2012 with EPS level >0.85 ($r = 0.75$, $P < 0.0001$) suggests common environmental forcing affecting growth dynamics of trees over the respective sites.

Dating of Himalayan cedar tree core samples using dendrochronological methods showed the oldest tree age of 477 years (AD 1536–2012) in Jageshwar. Thus the age of the oldest tree recorded by us extends back to the early 16th century. Nonetheless, in Jageshwar forests we also recorded several snag woods, girth of which exceeded that of the sampled trees (~9 m). This indicates that the period of plantation of Himalayan cedar around temple complexes could be even earlier than the early 16th century. The trees sampled from Gangolihat are relatively younger to those in Jageshwar, indicating that the plantation of Himalayan cedar could have started first in Jageshwar temple area, which gradually spread to other regions in Kumaon. The ring-width chronology statistics such as mean sensitivity (Table 1) and significant correlation between two site chronologies is similar to other climate-responsive Himalayan cedar chronologies developed elsewhere in the western Himalayan region[13–19]. To study the relationship between Himalayan cedar chronologies and climate, we performed cross-correlation analyses using climate data of Mukteshwar (29°28′N, 79°38′E, 2171 m amsl), the longest available data close to tree-ring sampling locations. The weather data of Mukteshwar show that bulk of precipitation (~73% of 1270 mm annual) occurs during monsoon season spread over June–September. The November–May precipitation occurring largely due to western disturbances is ~22% of the annual precipitation. To understand tree growth and climate relationship, climate data spanning from September of the previous growth year to current year September were used in correlations with the residual version of Himalayan cedar chronologies. The chronologies from both the sites showed similar relationship with monthly climate variables. The first principal component (PC#1) of two site chronologies with eigen value 1.752 explaining 87.6% of the variance in common chronology period (AD 1720–2012) showed the relationship with climate variables (Figure 4) to be similar to that observed with independent site chronologies. In correlation analyses, the precipitation from previous year September to current year May showed direct relationship with tree growth indices. The correlations were consistently positive and significant ($P < 0.05$) from February to May. However, no significant correlation was noted with precipitation during monsoon months (June–September) when precipitation is prevalent in the region due to active southwest summer monsoon. In case of temperature, negative relationship with mean monthly temperature of Mukteshwar for most of the months was noted, except during summer monsoon months (July–September), when it turned positive. The correlation analyses revealed that a cool-moist condition in premonsoon season is important for the radial growth of Himalayan cedar in Kumaon region. We are optimistic that such climate-responsive chronologies developed from a close network of sites in the Kumaon region would help in developing long-term records of premonsoon precipitation. In earlier studies, network of such ring-width chronologies from the western Himalayan region have been useful in developing long-term robust climate records[13–19].

We have developed annually resolved ring-width chronology of Himalayan cedar from groves in Jageshwar and Gangolihat temple complexes in Kumaon. The chronology from Jageshwar temple area extends back to AD 1536, whereas Gangolihat to AD 1668. The Himalayan cedar forests earlier claimed to be natural in Karnali Valley, Nepal are much younger than those in the Kumaon region. The sensitivity of ring-width chronologies to premonsoon precipitation underscores the utility of tree-ring data in developing long-term precipitation records for the data-scarce Kumaon region.

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