Moisture index during the last two centuries inferred from tree growth in the western Himalaya, India

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In the present study, a regional tree-ring chronology prepared from two species (*Picea smithiana* and *Cedrus deodara*) over the western Himalaya has been used in relation to climate fluctuations. This analysis shows that moisture index and rainfall during February to May have significant positive relationship, whereas temperature and heat index show a negative relationship with tree growth. However, moisture and heat indices show greater impact on tree growth than rainfall and temperature. The strong association of tree-ring chronology with moisture demonstrates that tree rings are much more sensitive to the availability of moisture at the root zone, which enabled us to extend our analysis back to AD 1789; in the present reconstruction, moisture deficiency for two consecutive years was noticed during 1846–1847, 1908–1909, 1921–1922, 1931–1932, 1947–1948 and 1966–1967.

Keywords: Moisture and heat indices, rainfall, temperature, tree rings.

THE western Himalaya has diverse climate (moist, moist subhumid, dry subhumid and semiarid) due to the geographical setting, high mountain ranges, variation in topography and orography. There is a large-scale variation in precipitation at short distances with changing mountain ranges and elevation. In the case of temperature, it is found to have a strong association spatially[1]. However, to understand the long-term variations in precipitation and temperature over the region, proxy records of several tree ring-width samples of conifers from the Himalaya have been performed in relation to climate variability/change[2–7]. They have shown good potential of Himalayan tree ring data for dendroclimatic analysis. However, all these studies are based on rainfall and temperature only. Reconstruction of moisture index (MI), which is a function of rainfall and temperature[8], is not yet available in a longer perspective over the region. Therefore, in the present study, we have reconstructed MI for the last two centuries. Such climatic records may help understand the past behaviour of availability of moisture at the root zone of trees.

In this context, ring-width data of *Picea smithiana* and *Cedrus deodara* from two sites (Dhanolti and Jageswar) in the western Himalaya have been used to study tree growth–climate relationship[3,4] (Figure 1). Site information, number of core samples per tree and their standardization techniques have already been discussed in a previous study[4]; consistently strong correlation was observed during the chronology length[4]. However, to check the spatial coherence in chronology, inter-correlations were performed for the period 1838–1990, based on a 50-year window with overlapping of 25 years. Correlation coefficients (CCs) ranged from 0.28 to 0.61, and were significant at 5% level, indicating common forcing, i.e. climate. Such strong correlations enabled us to prepare a regional chronology by merging tree core samples of the two sites to develop a robust climate reconstruction (Figure 1). A total of 25 core samples were considered in the present study and their ring-width measurement and crossdating were checked using COFECHA software[9].

All ring-width series were detrended using ARSTAN[10]. To obtain the common signal among the samples, double detrending process was adopted for all the series. First, ring-width data were standardized by a linear or negative exponential method to remove biological growth[11]. The resulting indices were detrended once again by 35-year cubic smoothing spline for reducing the remaining trends[11]. The obtained indices were prewhitened using autoregressive model based on the Akai information criterion to minimize the persistent low-frequency signal[11], and combined these indices across all the series to prepare a mean chronology[12].

Tree-ring data like mean sensitivity (0.21), variance (0.31), expressed population signal (0.87) and signal-to-noise ratio (6.5) showed the greater impact of climate on the tree rings. The threshold value (0.85) of the expressed population signal (EPS) was found to be above that reported since AD 1788 (figure not shown), which indicated reliability and stability of chronology for dendroclimatic analysis[3,12]. However, the noisy data associated with poor replication of tree core samples were discarded and chronology was truncated to AD 1788 based on the performance by EPS[3,12].

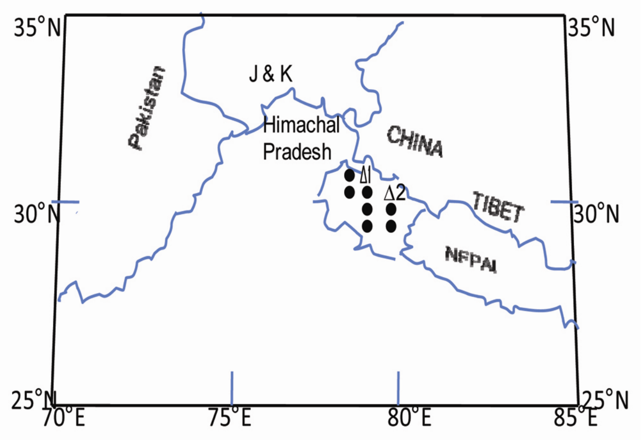

Figure 1. Map showing the study area. Δ1 and Δ2, Tree-ring width sites; •, Grid point climatic data.

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Table 1. Statistical tests performed during the calibration and verification periods for reconstruction of moisture index

	Calibration			Verification			
Period	F	R	V	Period	r	Pmt	RE
1901–1945	39.2**	0.69**	47.6%	1946–1990	0.50**	6.26**	0.47
1946–1990	11.6**	0.48**	23%	1901–1945	0.70**	3.97**	0.43
1901–1990	47.4**	0.60**	36%				

**Significant at 0.1%.

R, Multiple correlation coefficients; V, Variance explained; r, Correlation coefficients between actual and reconstructed moisture index; Pmt, Product mean test; RE, Reduction of error[19].

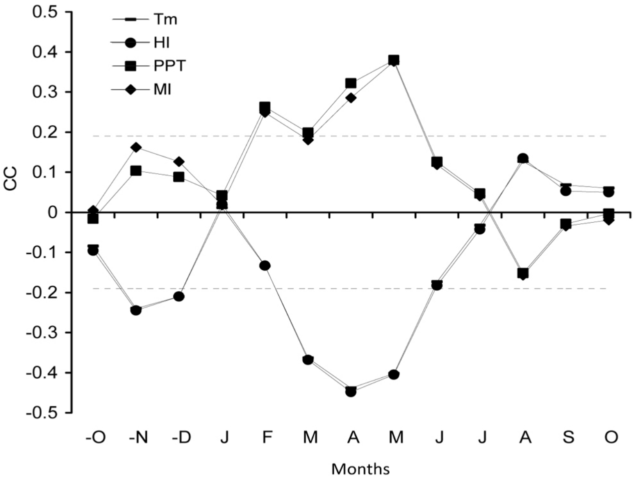

Figure 2. Correlations of tree- ring chronology with heat index HI (–●–), Temperature (TM) (——), rainfall (PPT) (–■–) and moisture index (MI) (–◆–). Dashed lines are significant at 5% level.

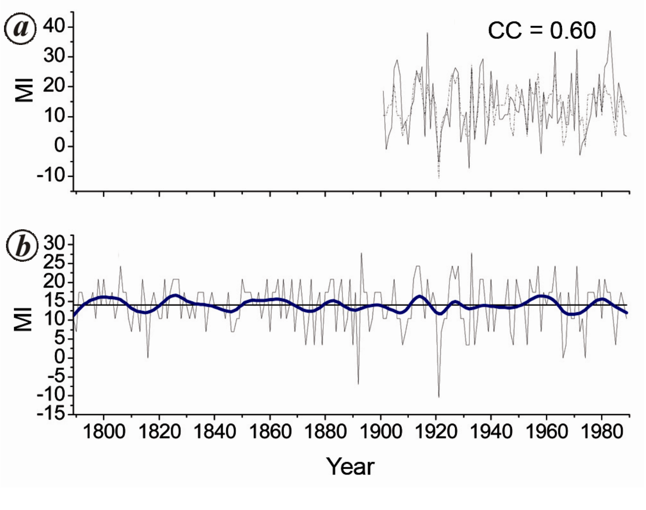

Figure 3. ***a***, Variations in actual (solid) and reconstructed MI (dashed). CC, Correlation coefficient. ***b***, Reconstructed MI during 1789–1990. Blue smoothened line shows 30-year cubic spline fit.

To analyse the relationship between chronology and climate data, the grid boxes (30.75°N, 78.25°E; 30.25°N, 78.25°E; 30.25°N, 78.75°E; 29.25°N, 78.75°E; 29.75°N, 78.75°E; 29.25°N, 79.25°E; 29.75°N, 79.25°E) of rainfall and temperature have been taken from CRU[13] (Figure 1). A regional series for precipitation and temperature was prepared for the period 1901–2002. In addition, MI and heat index (HI) were computed in relation to trees growth variations[8,14].

The correlation analysis between residual chronology and HI, temperature (Tm), rainfall (PPT) and MI was performed on a monthly basis (Figure 2). In Figure 2, the dashed horizontal lines are significant at 5% level. The significant positive association between a chronology and MI and PPT was observed during current year February, March, April and May. For Tm and HI, chronology showed significant negative relationships during November and December of the previous year, and the current year March, April and May.

Based on relationship, an analysis has been made to know the impact of seasonal climate on growth variations of trees during February to May. CCs between a chronology and HI, Tm, PPT and MI were –0.53, –0.49, 0.57 and 0.60 respectively, showing significance at 0.01% level. The analysis showed that seasonal climate has greater impact on tree growth variations than a single climatic parameter[15,16]. However, the relationship of tree growth with HI and MI was found stronger than that with temperature and rainfall. The results show that MI, which describes soil moisture availability at the root zone of the trees, plays a significant role in early wood formation[17], whereas increased HI is not found conducive to tree growth due to high potential evapotranspiration[16].

However, MI which showed the highest CC with tree growth was estimated to the past two centuries based on chronology of tree rings. In the regression model, tree-ring chronology with lead/lag of one year, i.e., t_{t+1}, t_0 and t_{t-1} was selected as predictor and MI as predictand[18]. MI was split in two sub-periods, i.e. 1901–1945 and 1946–1990, so that statistical tests could be compared against each sub-period. The first sub-period model accounted for 47.6% of the variance, whereas the calibration model of the second sub-period accounted for 23% of the variance (Table 1), weaker than the first calibration model, but showed the highly significant correlation (*r*), Pmt, and RE (Table 1). These results indicate reliability in tree growth–climate relationship[19]. Based on the various statistical tests, a calibration model for the full period

(1901–1990) was developed to extract the maximum low-frequency variation in reconstruction (Table 1). The reconstruction showed good year-to-year agreement and was highly correlated with actual data (Figure 3 *a*).

Figure 3 *b* shows the reconstructed MI back to AD 1789. Smoothened line in the figure shows cubic smoothing spline fit of 30 years. During the years 1798, 1800, 1806, 1814, 1822, 1825–1827, 1850, 1859, 1863, 1865, 1868, 1871, 1875, 1882–1883, 1886, 1889, 1893, 1905, 1912–1914, 1917, 1925–1928, 1933, 1936–1937, 1940, 1946, 1949, 1954, 1957, 1963, 1971, 1979 and 1981, high MI values (more than mean ± 1 SD) were noticed in the present reconstruction. It shows that the moist climate (humid) during spring season plays an important role in trees growth, whereas moist subhumid climate (less than mean-1std) during 1790, 1810, 1813, 1816, 1837, 1846–1847, 1860, 1869, 1873, 1876, 1879, 1884, 1887, 1890, 1892, 1896, 1908–1909, 1921–1922, 1931–1932, 1934, 1939, 1941, 1947–1948, 1953, 1958, 1966–1967, 1972, 1974 and 1985 might suppress trees growth[16].

To verify the present reconstruction, we have compared it with an earlier reconstruction by Yadav *et al.*[20], who also reported drought year in 1920–1924, 1812–1816, 1965–1968 and pluvial phase in 1791–1792, 1911–1915. Cook *et al.*[21] and Ram[22] also showed low soil moisture availability during 1848–1849, 1887–1897, 1933–1949 and 1965–1973, which is similar to our reconstruction. Overall, the present reconstruction shows somewhat similar patterns with previous reconstructions. However, some differences exist between the present and previous reconstructions, which could be due to geographical settings of the western Himalaya, or usage of a new climatic parameter, which is different from the previous reconstructions.

Moisture deficiency noticed during two consecutive years, i.e. 1846–1847, 1908–1909, 1921–1922, 1931–1932, 1947–1948 and 1966–1967, motivates us to prepare a longer chronology with good replication of samples, so that MI and HI could possibly be reconstructed even to further back in time. Monitoring the historical records of climate for the past several centuries over the region may be useful for a better understanding of past extreme events (driest and wettest). This type of study is useful in forest management, water resources and for sustainable development over the region.

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