Climatic response of various tree ring parameters of fir (*Abies pindrow*) from Chandanwadi in Jammu and Kashmir, western Himalaya, India

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Total ring width (TRW) and earlywood width (ERW) of fir (*Abies pindrow*) compared to latewood width (LRW) are strongly correlated with Palmer Drought Severity Index (PDSI) during summer season (March to October). Correlation coefficients for the period 1876–1948 between PDSI and TRW as well as ERW are 0.43 and 0.50 respectively, which is found to be significant at 0.01% level. Thereafter, their relationship weakened as temperature changed over the region, whereas maximum latewood density (MXD) reveals significant negative association with PDSI during summer season. Moreover, monthly mean, maximum and minimum temperatures during August to September of the region indicate significant positive response with MXD. Correlation coefficients of MXD with mean, maximum and minimum temperatures are 0.60, 0.61 and 0.51 respectively, which is significant at 0.01% level. There is also high temporal stability in the relationship between MXD and temperature from 1916 onwards over the region.

Keywords: *Abies pindrow*, climate variability, earlywood width, latewood width,

THE high mountain ranges of the Himalaya, especially due to varying elevation gradient, have strong influence on regional climate. Due to short period of climatic data with limited parameters and paucity of close weather stations, long-term climate variations are not well understood over the region. Thus, for better understanding of climate where weather station is not available, dendroclimatic studies over the western Himalaya have been carried out by several scientists using a wide network of tree-ring data[1–7]. Ring-width index chronologies reveal positive relationship with precipitation during March to July and negative relationship with pre-monsoon temperature[8,9]. It is also evident from several dendroclimatic reconstructions that Little Ice Age (LIA) and Medieval Warm Period (MWP) were not significant over the western Himalayan region, except a few cold and warm epochs. Precipitation and temperature for spring season have been reconstructed back to several centuries[1,7,10]. Few studies[11–13] also indicate the vital role of moisture availability (e.g. Palmer Drought Severity Index (PDSI)) at the root zone on tree growth in comparison to rainfall.

Moreover, some dendroclimatic studies have also been conducted in western Himalaya using wood density parameters[14–16]. It was noticed that minimum earlywood density (NXD) parameters are strongly related to climate, showing significant positive relationship with temperature and negative relationship with precipitation during spring season[14]. However, MXD did not show significant relationship with the local climate. Most of the above studies are based on the tree-ring width data and their relationship with meteorological station data of rainfall and temperature. Sometimes, meteorological stations are located far from the tree-ring sites, which results in complications in understanding the tree growth–climate relationship.

In view of this, in the present study we analysed several tree-rings parameters [total ring width (TRW), earlywood width (ERW), latewood width (LRW), maximum latewood density (MXD), and minimum earlywood density (NXD)] of fir (*Abies pindrow*) from Chandanwadi, Jammu and Kashmir and their relationship with ambient climate close to sampling sites to assess the influence of various climatic parameters (PDSI, precipitation, mean, maximum and minimum temperatures) on different tree-rings parameters. This communication presents preliminary results of TRW, ERW, LRW, MXD and NXD and their association with long-term climatic variability/change in the region which may provide a better understanding of tree growth–climate relationship.

Data of tree-ring parameters of fir were used from the NOAA website (http://www.ncdc.noaa.gov/paleo/treering.html). Various parameters (TRW, ERW, LRW, MXD, NXD) of high-altitude fir trees from Chandanwadi (34°15′N, 75°55′E or 34.25°N, 75.92°E, 3200 m a.s.l.), created by Hughes[16], have been reinvestigated in the present study (Figure 1). There are a total of 10 cores from 10 trees. The program COFECHA was used for all the dated ring-width measurements for missing and datings error of

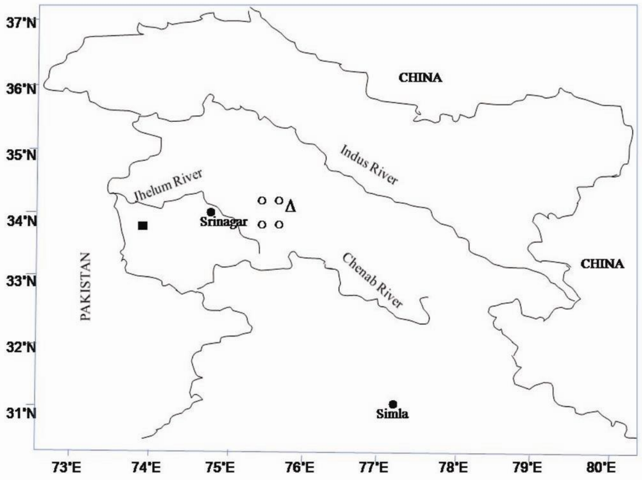

Figure 1. Location of the study area. (△) Tree-ring parameters; (○) grid box climate data; (■) PDSI.

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Table 1. Statistics of five-parameter tree-ring chronologies (values inside brackets are with AR)

	Type of parameter				
	TRW	ERW	LRW	MXD	NXD
Chronology time-span	1777–1981	1777–1981	1777–1981	1777–1981	1777–1981
MS	0.16 (0.18)	0.16 (0.19)	0.27 (0.27)	0.06 (0.06)	0.03 (0.04)
SD	0.18 (0.16)	01.9 (0.17)	0.27 (0.26)	0.05 (0.05)	0.04 (0.04)
AC1	0.47 (–0.2)	0.45 (0.01)	0.09 (0.01)	0.13 (–0.05)	–0.02 (–0.09)
Common period analysis	1860–1981	1860–1981	1860–1981	1860–1981	1860–1981
EPS	0.80 (0.75)	0.79 (0.73)	0.73 (0.71)	0.79 (0.80)	0.31 (0.30)
SNR	4.0 (2.9)	3.7 (2.8)	2.7 (2.4)	3.7 (3.9)	0.46 (0.43)
Rbar	0.45 (0.37)	0.43 (0.36)	0.40 (0.38)	0.43 (0.44)	0.08 (0.07)

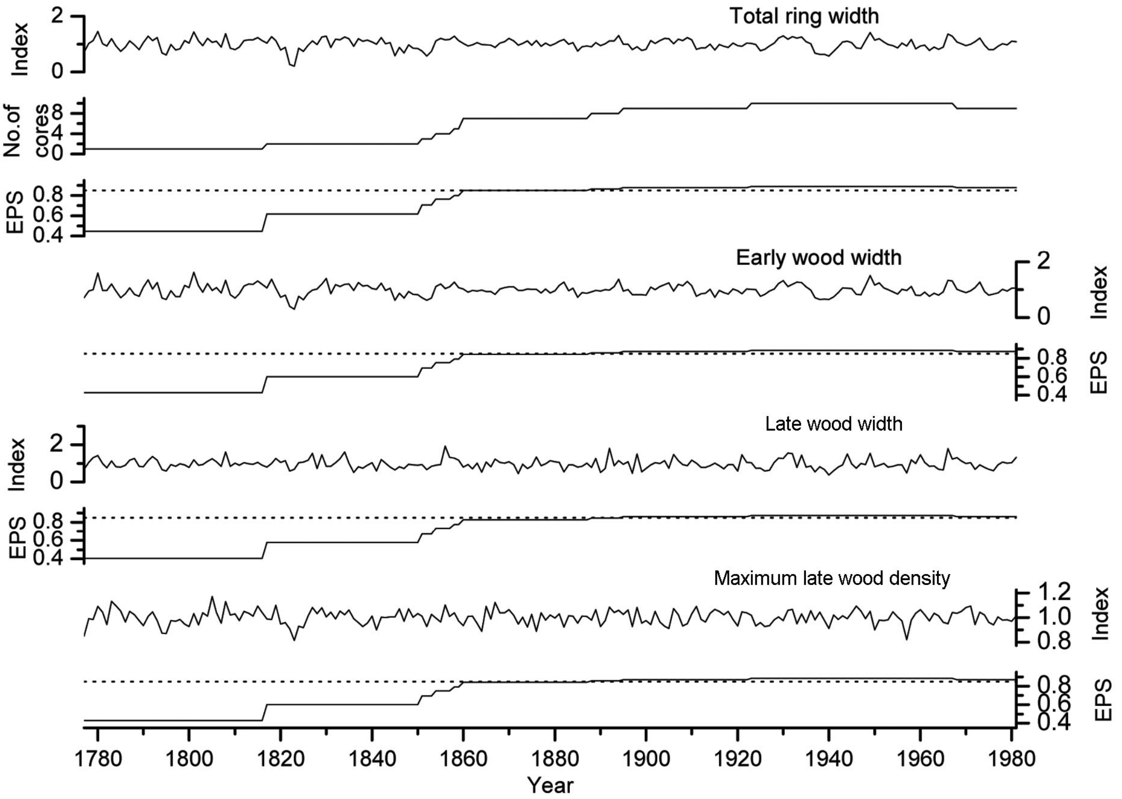

Figure 2. Tree-ring chronologies of multi parameters along with number of cores and EPS. Horizontal dashed lines are threshold of 0.85.

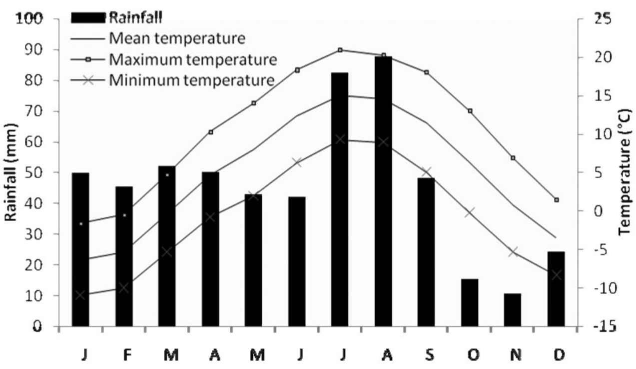

Figure 3. Mean monthly variation in precipitation and mean, maximum and minimum temperatures over the region during 1901–2002.

the series[17]. All tree-ring-width parameters were standardized to dimensionless indices by using the traditional program ARSTAN[18]. Based on the characteristics of ring-width series, double detrending was performed in the case of each series. First, either a negative exponential or linear regression function was applied to all series to remove the non-climatic signal which is associated with tree ageing. Then the resulting series were again detrended with a cubic spline of 35 years for removing other non-climatic signals, i.e. associated with stand dynamics.

Autoregressive model (AR) was used to remove the persistence of lag 1 autocorrelation from the tree-ring series for producing pre-whitened 'residual' indices[18]. All detrended series were averaged to produce a mean site

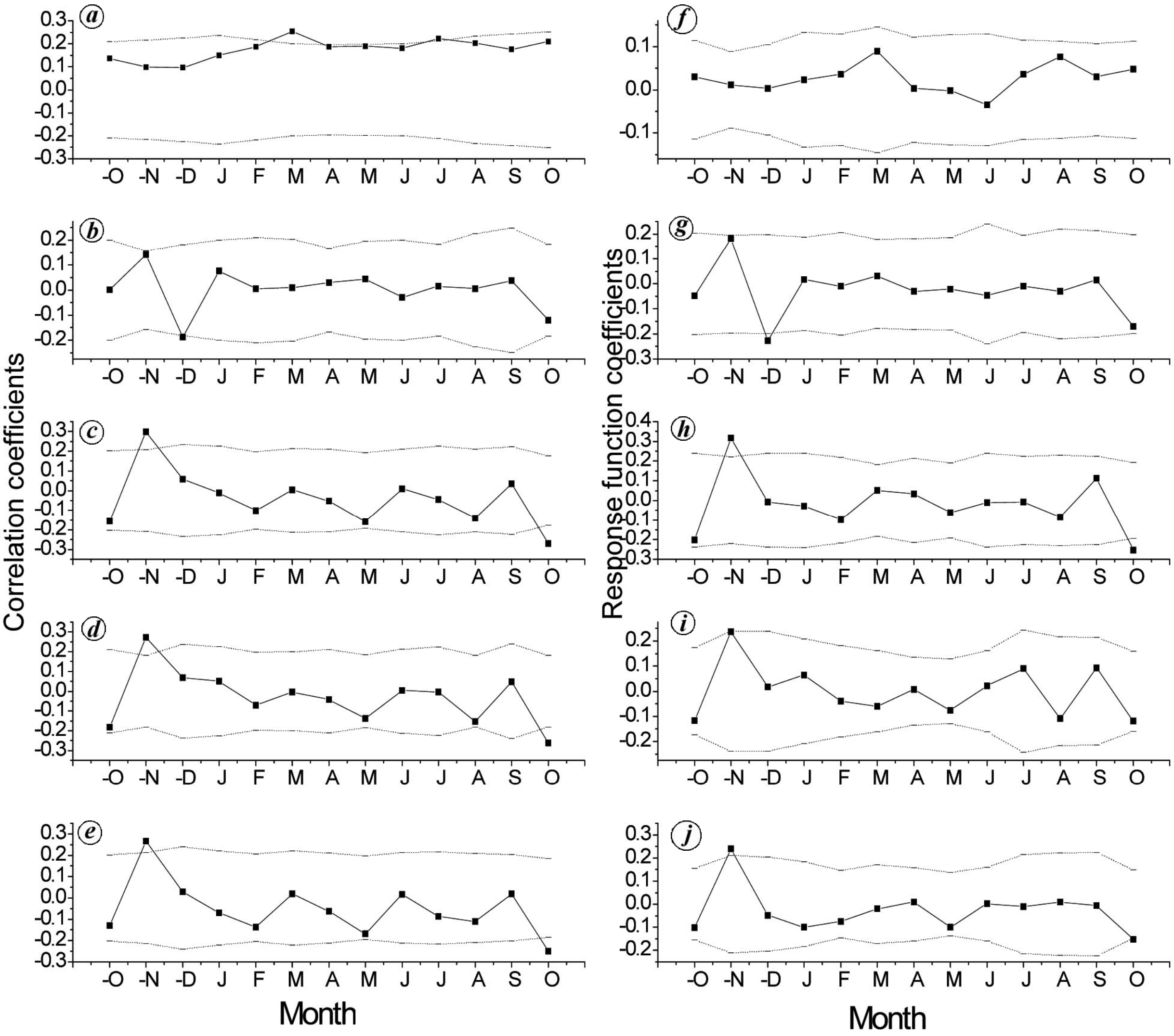

Figure 4. Correlation coefficients of TRW with (*a*) PDSI, (*b*) precipitation, (*c*) mean temperature, (*d*) maximum temperature and (*e*) minimum temperature. Response coefficients of TRW with (*f*) PDSI, (*g*) precipitation, (*h*) mean temperature, (*i*) maximum temperature and (*j*) minimum temperature. Dashed lines indicate 95% confidence limits.

Table 2. Inter-correlation among chronologies during 1777–1981

	TRW	ERW	LRW	MXD
TRW	1	0.96***	0.56***	0.30***
ERW		1	0.41***	0.20**
LRW			1	0.54***
MXD				1

***Significant at 0.01% level; **Significant at 0.1% level.

chronology by calculating biweight robust mean to remove the influence of outliers[19]. Several descriptive statistics of TRW, ERW, LRW, MXD and NXD before and after AR are shown in Table 1. These include mean sensitivity (MS), standard deviation (SD), first order autocorrelation (AC1), expressed population signal (EPS), signal-to-noise ratio (SNR) and common variance (Rbar) as shown by Fritts[20]. Tree-ring chronologies of multi-parameters along with the number of cores and EPS are shown in Figure 2.

Due to sparse and limited meteorological stations in and around the sampling area, monthly mean, maximum and minimum temperatures, and precipitation of the four grid boxes (33.75°N, 75.25°E; 33.75°N, 75.75°E; 34.25°N, 75.25°E; 34.25°N, 75.75°E) were used from Climate Research Unit[21] (CRU; Figure 1). The strong coherence in precipitation and temperature data allowed for preparing a regional series. The monthly regional series of rainfall and temperature was prepared by taking mean of all grid-point data. Based on the long-term average, climatic conditions in and around the study area are shown (Figure 3). July is the hottest month and August the wettest with 87.8 mm rainfall. Good amount of

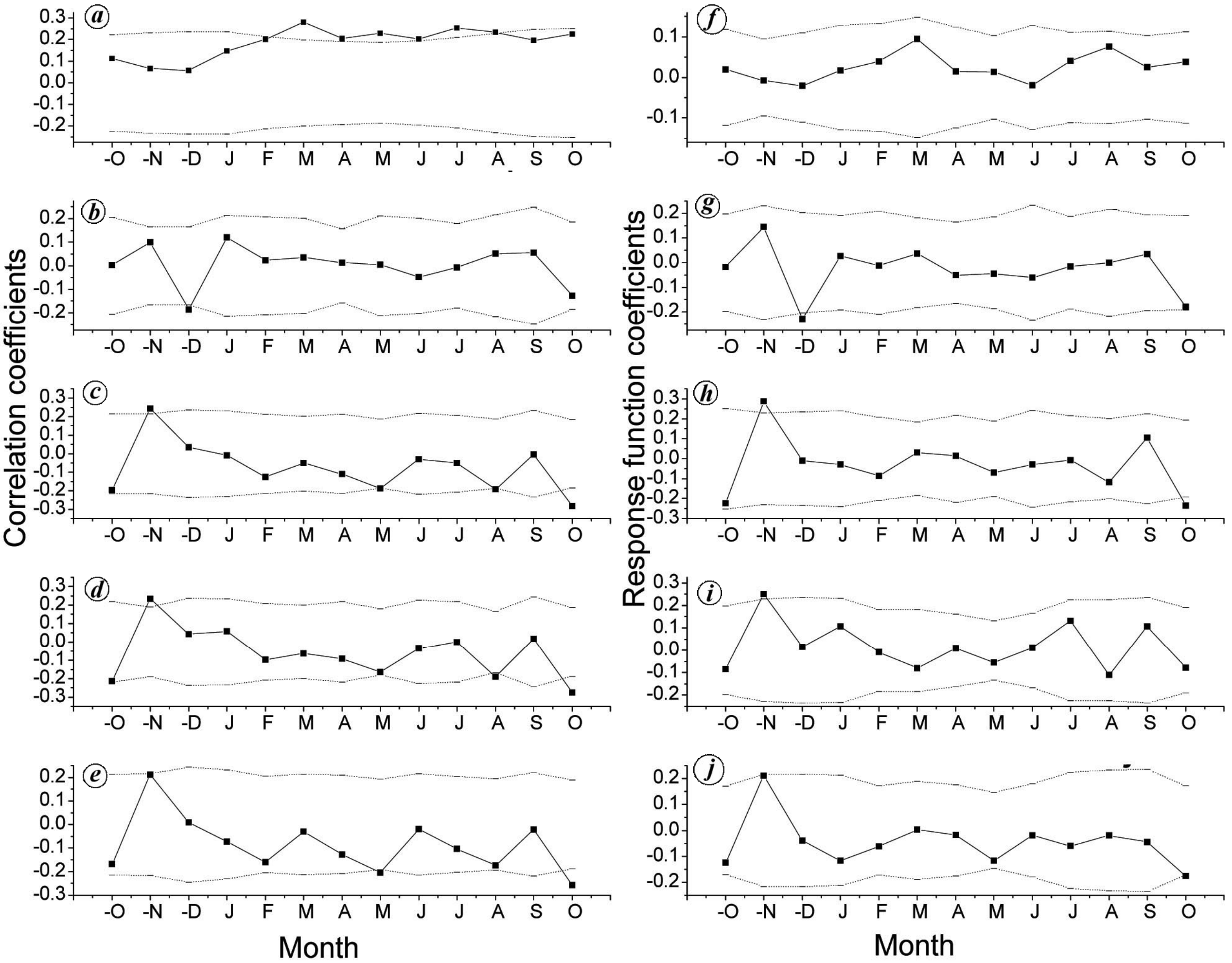

Figure 5. Correlation coefficients of ERW with (***a***) PDSI, (***b***) precipitation, (***c***) mean temperature, (***d***) maximum temperature and (***e***) minimum temperature. Response coefficients of ERW with (***f***) PDSI, (***g***) precipitation, (***h***) mean temperature, (***i***) maximum temperature and (***j***) minimum temperature. Dashed lines indicate 95% confidence limits.

rainfall occurs during the non-monsoon months over the region, as shown in Figure 3. In addition, for better understanding of tree growth–climate relationship, the continuous records of PDSI (33.75°N, 73.75°E) were also used in the analysis[22]. Correlation and response function analysis was carried out using the program DENDROCLIM2002 (ref. 23).

Table 1 reveals the statistics of tree-ring chronologies produced by ARSTAN program[18]. Generally, high MS, SD, EPS, SNR and Rbar show the strong environmental influence on tree growth[19]. In case of residual chronology of TRW, ERW and LRW, EPS, SNR and Rbar are slightly lower compared to the MXD residual chronology (Table 1). AC1 of TRW, ERW, LRW and MXD is 0.47, 0.45, 0.09 and 0.13 respectively, showing the presence of somewhat low-frequency variance in the standard chronology. However, NXD revealed low EPS, SNR and Rbar (Table 1). Due to poor statistics of NXD, it has not been included in further analysis (Table 2). Time series of TRW, ERW, LRW and MXD are plotted in Figure 2 along with cores and EPS, except NXD. Horizontal dashed lines are threshold of 0.85, as shown by Wigley *et al.*[24].

Based on the chronologies statistics, it is observed that AR which was applied to produce a residual chronology not only filtered the lag effects but also removed some important climatic information from the ring-width series (Table 1), as shown by Cook and Kairiukstis[19]. In standard chronologies, high- and low-frequency signals are included. But, in residual chronology, there is only high-frequency signal, i.e. climate. These results show that standard tree-ring chronologies might have better environmental information than the residual chronologies as shown in Table 1. Inter-correlation among standard chronologies is shown in Table 2. All correlation coefficients are found to be significant at 0.1% level and above. The significant positive correlations among chronologies are good indicators of common forcing, i.e. climate. Therefore, standard chronologies of the tree-ring parameters were used in further analysis.

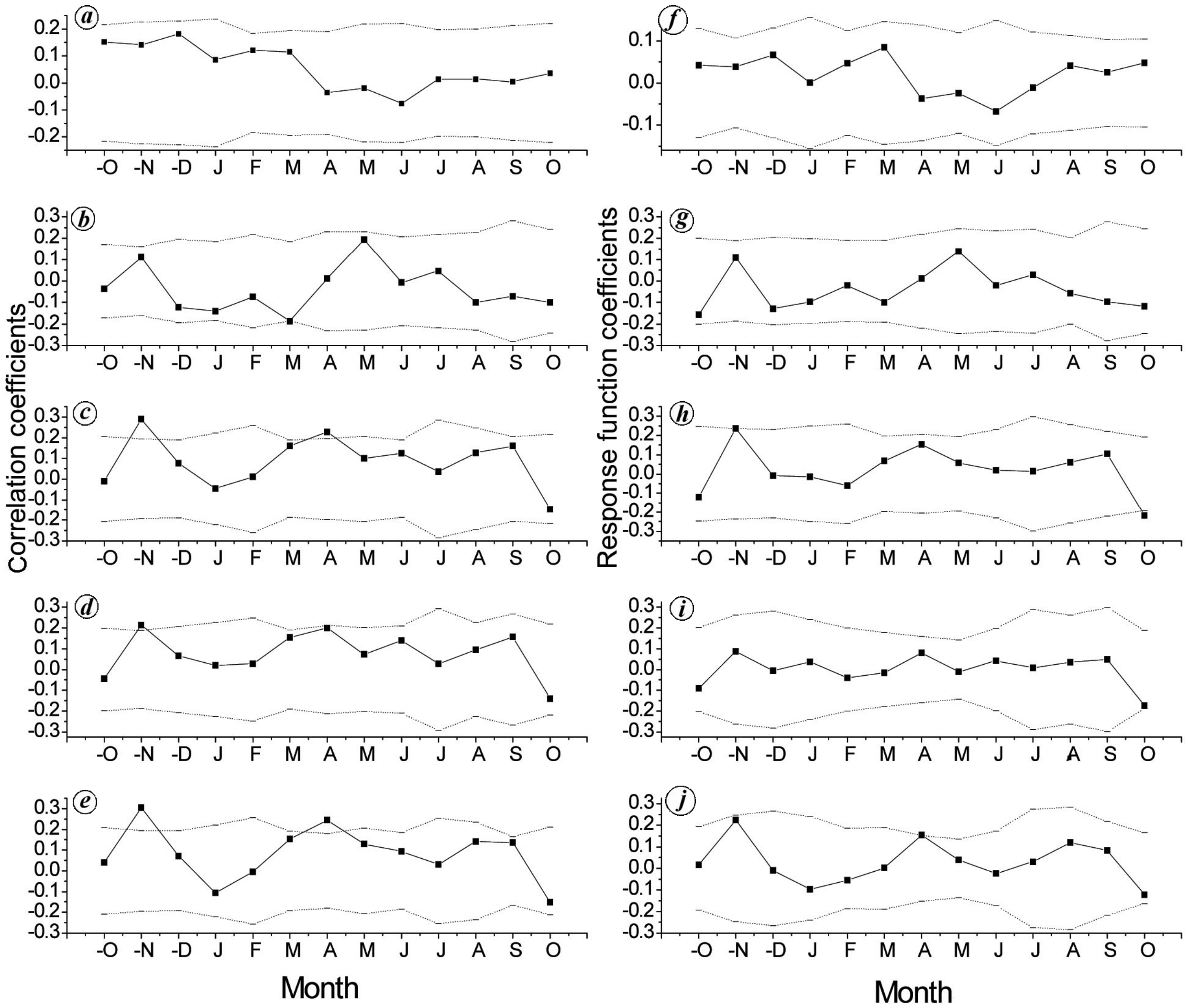

Figure 6. Correlation coefficients of LRW with (*a*) PDSI, (*b*) precipitation, (*c*) mean temperature, (*d*) maximum temperature and (*e*) minimum temperature. Response coefficients of LRW with (*f*) PDSI, (*g*) precipitation, (*h*) mean temperature, (*i*) maximum temperature and (*j*) minimum temperature. Dashed lines indicate 95% confidence limits.

Tree growth–climate relationship study has been carried out using the program DENDROCLIM2002 (ref. 23), which uses bootstrapping to reduce potential error and obtain more accurate results[25]. The relationships between various tree-ring parameters (TRW, ERW, LRW and MXD) and several climatic variables (PDSI, precipitation and mean, maximum and minimum temperatures) for a 13-month interval starting from previous year October (ending of growing season) to current year October (ceasing of growing season) were investigated in order to understand the impact of climatic conditions on tree growth during current and prior year growing seasons (Figures 4–7). Correlation and response function coefficients that equal or exceeded the 95% confidence level are shown in Figures 4–7.

The relationship between tree-ring parameters and climatic variables is displayed in Figures 4–7. Significant positive relationship was found among TRW, ERW and mean, maximum and minimum temperatures of prior year November (Figures 4 *c–e*, 4 *h–j*, 5 *c–e*, 5 *h–j* and 6 *c–e*, 6 *h–j*). Only maximum temperature in Figure 6 *i* reveals weak but positive relationship with LRW. Overall the results show that the increased temperature during November of the prior year over the region is responsible for advanced snow melt run-off which would maintain enough moisture during physiological processes and growing season of the trees. These results, in general, are consistent with the findings of Ram and Borgaonkar[13] and Yadav *et al.*[26]. The increasing mean, maximum and minimum temperatures during October of the current year are not found to be favourable for TRW, ERW and LRW (Figures 4 *c–e*, 4 *h–j*, 5 *c–e*, 5 *h–j* and 6 *c–e*, 6 *h–j*). However, correlation coefficients between LRW and mean, maximum and minimum temperatures were observed to be weaker but barely significant (Figure 6 *c–e*). This indicates that the increased temperatures during

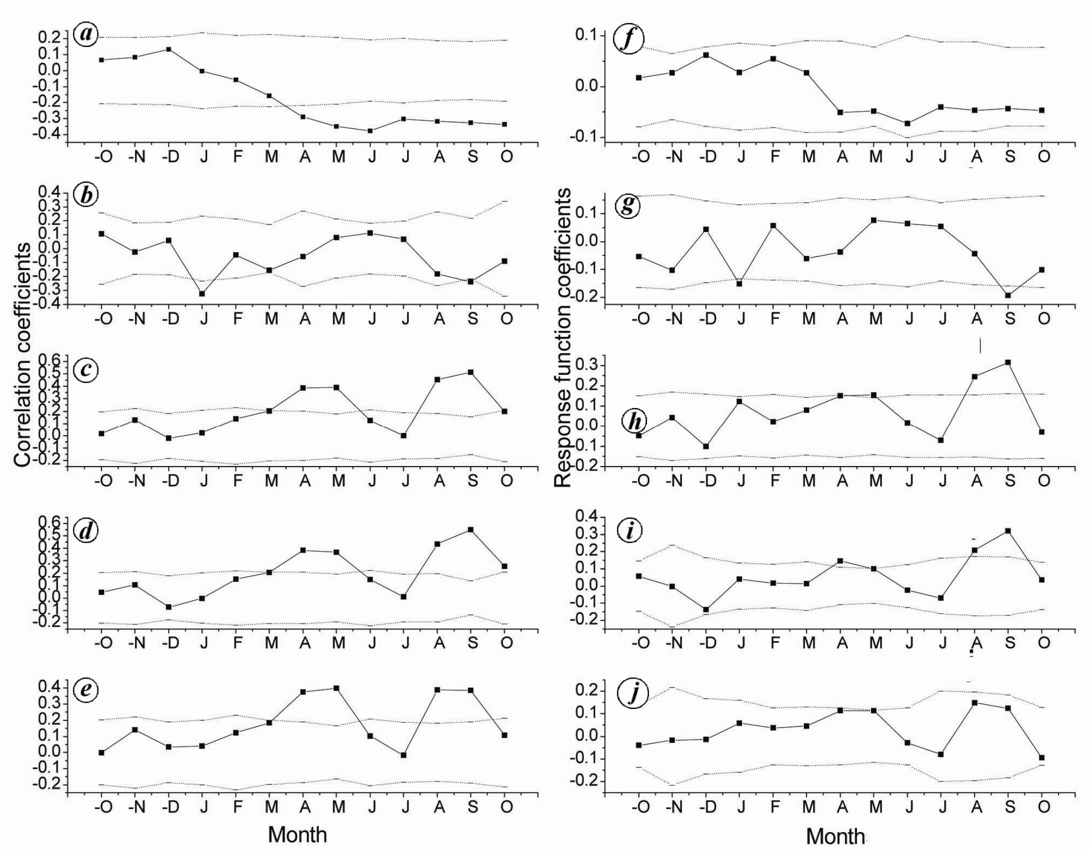

Figure 7. Correlation coefficients of MXD with (a) PDSI, (*b*) precipitation, (*c*) mean temperature, (*d*) maximum temperature and (*e*) minimum temperature. Response coefficients of MXD with (*f*) PDSI, (*g*) precipitation, (*h*) mean temperature, (*i*) maximum temperature and (*j*) minimum temperature. Dashed lines indicate 95% confidence limits.

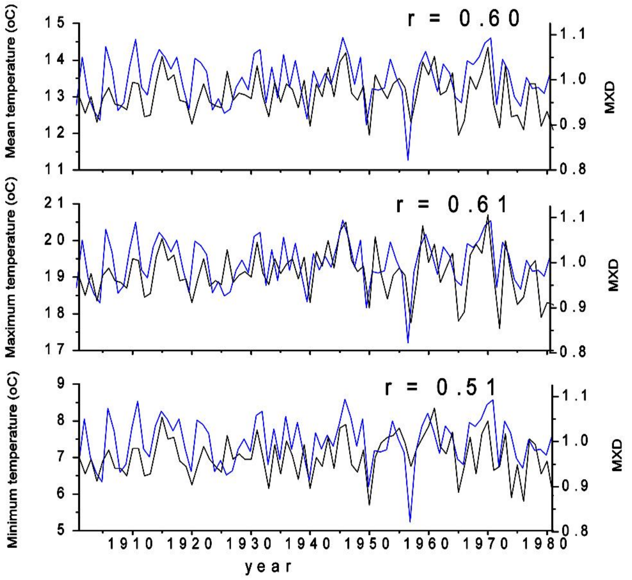

Figure 8. Variations in MXD (blue line) and mean, maximum and minimum temperatures (black line) during August–September. *r* is the correlation coefficient.

the current year October might reduce the soil moisture availability for subsequent year growing season of the trees.

In case of PDSI, significant positive relationships were noted with TRW and ERW chronologies during March to July (Figures 4 *a* and 5 *a*). Such significant correlations between precipitation and TRW as well as ERW are not observed (Figures 4 *b* and 5 *b*). This indicates that the PDSI which displays moisture availability over the region, has significant role on TRW and ERW compared to LRW, showing positive relationship during the entire growing season of the tree (March–October; Figures 4 *a* and 5 *a*). TRW and ERW respond strongly to PDSI compared to LRW. The reason for weak correlation between LRW and PDSI is not well understood. However, we found that the latewood width does not increase proportionally like earlywood width (figure not shown) and this could be the possible reason for the weakened relationship.

In the case of MXD, PDSI from April to October is not found to be conducive over the region (Figure 7 *a*). It shows significant negative association with MXD. Whereas, mean, maximum and minimum temperatures during April–May and August–September have significant positive relationship with MXD, which shows favourable condition for MXD (Figure 7 *c*–*e*, *h*, *i*) however, minimum temperature during August–September shows weak but positive relationship with MXD (Figure 7 *j*). It reflects that mean, maximum and

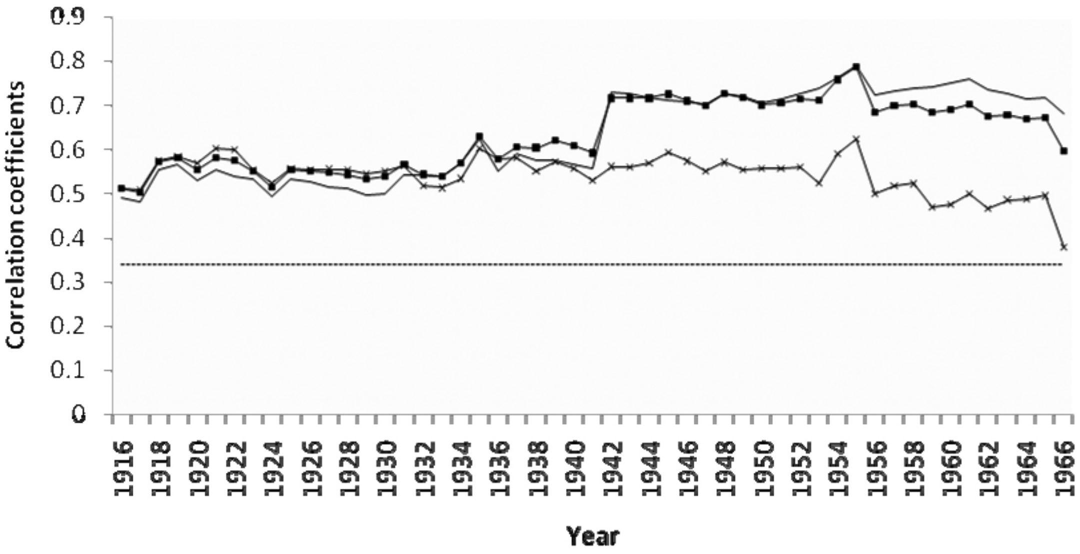

Figure 9. The 31-yr sliding correlation between MXD and mean (–■–), maximum (solid line) and minimum temperatures (–×–) during 1901–1981. Correlation coefficients are plotted against the central year of the 31-yr period. Dashed line parallel to the *x*-axis indicates significance at 5% level.

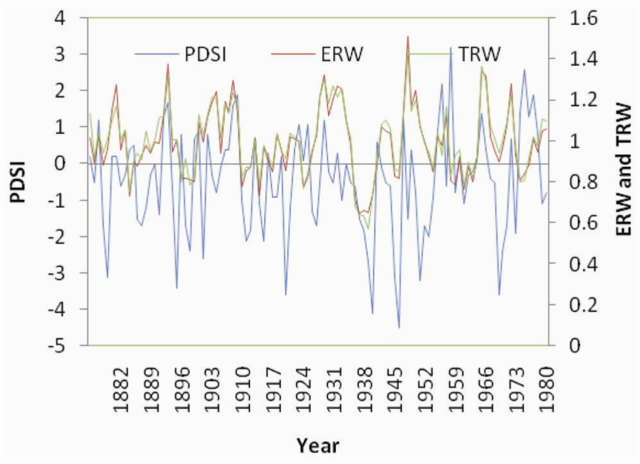

Figure 10. Variations in TRW, ERW and PDSI during summer season (March to October) for the common period 1876–1981.

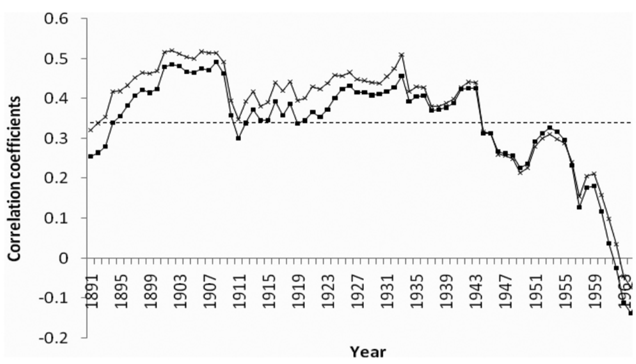

Figure 11. The 31-yr sliding correlation between summer PDSI and TRW (–■–) and ERW (–×–). Correlation coefficients are plotted against the central year of the 31-yr period. Dashed line parallel to the *x*-axis indicates significance at 5% level.

minimum temperatures during April–May and August–September of the region are favourable for MXD (Figure 7 *c–e*, *h–j*). Borgaonkar *et al.*[14] have also shown that tree-ring density parameters over western Himalaya are more sensitive to temperature.

Moreover, as shown in Figure 8, the correlation coefficients for the period 1901–1981 between MXD and mean (top), maximum (middle) and minimum (bottom) temperatures during late summer season (August–September) are 0.60, 0.61 and 0.51 respectively, which is highly significant at 0.01% level. Also, a 31-yr sliding correlation analysis for common period was carried out to check the temporal stability in relationship between MXD and mean, maximum and minimum temperatures (Figure 9). The relationship is stable from 1916 onwards. However, after 1941, the correlation coefficients between MXD and mean and maximum temperatures increased rapidly compared to early period. Particularly, mean and maximum temperatures have strong impact on MXD during the recent few decades (Figure 9). The increased correlations indicate that some changes have taken place, which need to be studied further. Long-term changes in temperature may be one of the causes which modify the response of tree growth behaviour in the recent few decades. Yasue *et al.*[27] also demonstrated that MXD is more sensitive to climate over northern Japan. Hughes *et al.*[28] have also shown the reconstruction of rainfall series since AD 1600 over north-central China using MXD. Ramesh *et al.*[29] showed that the increased temperature during late summer monsoon might promote the rate of photosynthesis of trees. However, the role of significant month/season of climatic variables on tree growth processes may not be the same at all the sites due to differences in microclimate, topography, geological setting and other factors over the region which have not been included in the analysis.

Based on the significant response shown by monthly climatic parameters to tree growth (TRW, ERW; Figures 4 *a* and 5 *a*), a single season from March to October of PDSI was prepared to extract a common climatic signal during the entire growing season of trees (Figure 10). The seasonally averaged PDSI was found more useful than single-month PDSI in tree growth processes[13,30]. TRW and ERW are directly proportional to PDSI as shown in Figure 10. The relationship for the period 1876–1948 between PDSI and TRW as well as ERW was 0.43 and 0.50 respectively, which is significant at 0.01% level (Figure 10). Thereafter, this relationship slightly weakened. Correlation coefficients between PDSI and TRW as well as ERW during 1949–1981 are –0.15 and 0.10 respectively (Figure 10). In addition, to compute the temporal stability between PDSI and TRW as well as ERW, a 31-yr sliding correlation analysis was performed between chronologies and PDSI. Both TRW and ERW show almost stable relationship with PDSI from 1894 to 1943 (Figure 11). Correlation coefficients between ERW and PDSI are higher than those between TRW and PDSI (Figure 11). This indicates that ERW compared to TRW is strongly influenced by the soil moisture of the region throughout the year. After 1944, the correlation coefficients have been rapidly decreasing since temperature has changed over the region. The causes for this weakening relationship are not known, but combined effects of multiple climatic parameters could be responsible. Our findings are also consistent with those of Ram and Borgaonkar[13,30].

The results on tree-ring parameters from a single site reveal that TRW and ERW are significantly influenced by the availability of soil moisture during the growing season of the trees, whereas MXD is more closely related to mean and maximum temperatures than minimum temperature in the recent few decades. Based on the relationship between tree growth parameters and ambient climate, it is observed that a good network of various tree-ring parameters from western Himalaya is more useful than only the total ring-width. This study has helped in a better understanding of tree growth–climate relationship and selection of predictors for robust reconstruction of past climate of the region. Such climatic reconstructions would be more reliable to understand the exact role of long-term climate variability on tree growth processes.

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Efficacy of two dominant marker systems, ISSR and TE-AFLP for assessment of genetic diversity in biodiesel species *Pongamia pinnata*

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The extent of genetic diversity was assessed in 12 *Pongamia* accessions from different regions of Delhi and surrounding areas using two dominant markers, namely ISSR and three endonuclease AFLP (TE-AFLP). Five ISSR primers and two TE-AFLP primer combinations generated a total of 12 and 48 polymorphic bands respectively. The Jaccard's dissimilarity coefficient ranged from 0 to 0.90 for ISSR and from 0 to 0.67 for TE-AFLP markers. The polymorphic information content of both markers was equal. However, TE-AFLP had much higher values of marker index and resolving power compared to those obtained for ISSR markers. This study demonstrates the usefulness of dominant markers like ISSR and TE-AFLP for assessment of genetic diversity in *Pongamia* for which microsatellites markers are still not available. However, high multiplex ratio, easy scorability and other high band attributes of TE-AFLP markers make them more suitable compared to ISSR for genetic diversity analysis.

Keywords: Dominant markers, genetic diversity, *Pongamia* accessions.

PONGAMIA pinnata L. Pierre (locally known as karanja), a member of the family Fabaceae, is a non-edible oil-producing tree which has been recognized as a major biodiesel species in India[1]. The species is indigenous to India and Southeast Asia, from where it has spread to other parts of the world. In urban areas it is a common avenue tree primarily grown for shade and aesthetic value due to its brilliantly coloured flowers and shiny leaves. Its seed oil content is about 32–42%, and can be converted into biodiesel which is at par with that of *Jatropha curcas*[2]. In the past few years *Pongamia* has attracted interest of several investors, including many from the United States as a biodiesel crop. However, availability of any improved and characterized planting stock has been the major bottleneck in harnessing the biofuel potential of this plant. A large proportion of trees do not flower at all and commercially attractive levels of fruiting are observed in only a small fraction of total trees[3]. There is a large phenotypic diversity in this species, thus providing an opportunity for genetic improvement[2]. More recently, initiatives have been taken towards identification of superior genotypes and their characterization.

Assessment of genetic diversity is a prerequisite for efficient conservation and utilization of genetic resources. During the past two decades, several high-throughput PCR-based technologies such as randomly amplified polymorphic DNA (RAPD), inter-simple sequence repeats (ISSR) and amplified fragment length polymorphisms (AFLP) have been developed to assay genetic polymorphism at the DNA level. Among these, RAPD[4], ISSR[5] and more recently, AFLP[6] have been increasingly used for detailed genetic analysis. All these technologies are accessible and they quickly provide large number of polymorphic markers with universal reagents and assay protocols without prior genetic information of the concerned species. However, due to their dominant behaviour, ISSR and AFLP markers have less information per locus than co-dominant markers. A number of studies have been conducted on *Pongamia* using dominant markers such as RAPD, ISSR, AFLP and TE-AFLP[3,7–10]. As there are not many microsatellite markers reported for *Pongamia*, the present study was aimed to assess the efficacy of two dominant markers in a set of 12 *Pongamia* accessions for analysis of genetic diversity.

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