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# Climatic implications of tree-ring density variations in Himalayan conifers

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## ABSTRACT

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The densitometric analysis of Himalayan conifers from six different sites reveals the strong association of ring density parameters with regional climate. Minimum earlywood density and total ring width are major contributors to the tree growth-climate relationship. It also indicates that pre-monsoon (March-April-May) temperature has significant positive relationship with earlywood density and significant negative correlation with total ring width. In case of precipitation, earlywood density gives negative relationship and ring width gives positive relationship with pre-monsoon precipitation. Latewood density parameters do not show any coherent pattern of relationship with climate. A strong association of earlywood density and ring width parameters may be due to severe moisture stress conditions occurring during the early phase of growing season of the conifers over the region.

**Key-words**—Conifers, Himalaya, Climate, Tree-ring density.

## हिमालयी शंकुवृक्षों के घनत्व वैविध्य के जलवायुविक निहितार्थ

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## सारांश

छः भिन्न-भिन्न स्थलों से प्राप्त हिमालयी शंकुवृक्षों के घनत्वमिति विश्लेषण से क्षेत्रीय जलवायु के साथ वलय घनत्व प्राचलों का दृढ़ साहचर्य प्रदर्शित हुआ है। वृक्ष वृद्धि-जलवायु सम्बन्धों के मूल्यांकन में न्यूनतम अग्रदारु घनत्व तथा सकल वलयी चौड़ाई प्रमुख भूमिका का निर्वाह करते हैं। इससे यह भी संकेत मिलता है कि मात्र मानसून पूर्व (मार्च-अप्रैल-मई) जलवायु (तापमान एवं वर्षण) का ही अग्रदारु घनत्व एवं सकल वलयी चौड़ाई के साथ महत्त्वपूर्ण सम्बन्ध है जबकि पश्चदारु घनत्व प्राचल जलवायु के साथ कोई प्रभावी सम्बन्ध नहीं प्रदर्शित करते हैं। अग्रदारु घनत्व प्राचलों का दृढ़ साहचर्य इस क्षेत्र में शंकु वृक्षों के वृद्धि करने की प्रारंभिक प्रावस्था के दौरान की भयावह आर्द्र प्रतिबल स्थितियों के कारण हो सकता है।

**संकेत शब्द**—शंकुवृक्ष, हिमालय, जलवायु, अग्रदारु.

## INTRODUCTION

OVER the western Himalayan region numerous tree-ring studies have been done using Himalayan conifers (Pant, 1979, 1983; Pant & Borgaonkar, 1984; Pant *et al.*, 1998; Hughes & Davies, 1987; Borgaonkar *et al.*, 1994, 1996, 1999; Bhattacharyya *et al.*, 1988; Bhattacharyya & Yadav, 1999). Tree-ring width index chronologies from different parts of the western Himalaya show significant relationship with pre-monsoon (March-April-May) temperature and precipitation (Borgaonkar, 1996; Yadav *et al.*, 1999). These results are based on only ring widths. However, ring density parameters are also important in dendroclimatic studies to better understand the tree growth-climate relationship at intra-annual to intra-seasonal scales (Schweingruber *et al.*, 1978).

Preliminary study by Pant *et al.* (2000) on tree-ring density parameters of Himalayan cedar (*Cedrus deodara* D. Don) indicates the important role of earlywood density in dendroclimatic modelling. Though their analysis was limited to a single conifer species from two nearby sites of western Himalaya, it primarily indicates the high potential of earlywood density of *Cedrus deodara* for climate reconstruction. In the present paper, dendroclimatic analysis was carried out using density parameters of four conifer species namely *Cedrus deodara* D. Don., *Picea smithiana* Boiss, *Abies pindrow* Spach and *Pinus roxburghii* Sargent from six different sites of western Himalaya to determine their utility in dendroclimatic reconstructions. This also includes the density chronologies of *Cedrus deodara* from two sites studied by Pant *et al.* (2000) to compare with the density chronologies from other western Himalayan sites.

## TREE-RING DATA

Eighty-one tree core samples from four different species of Himalayan conifers were analysed. Fig. 1 summarises the tree-ring site information. Ring density of the cores was measured at Forestry and Forest Products Research Institute, Tsukuba, Japan.

Cores were cut transversely to a thickness of 2 mm with a twin-bladed saw and oven dried. All samples were X-rayed with "soft" X-ray. The X-ray apparatus was EMBW-S type manufactured by SOFTEX. The distance between X-ray source and sample was set to 2·2 m with voltage 14 kV, current 12 mA and exposed time 4 minutes. The densitometric analysis of these x-ray radiographs was carried out on a DENDRO-2003 tree-ring workstation. Six parameters were measured on each tree-ring sample from transmitted image of the x-ray film to produce time series of earlywood, latewood, minimum, maximum and mean densities along with total ring width. The boundary between earlywood and latewood was identified as the mid point between the maximum and minimum density measurement of each ring.

All ring width series were checked with computer programme COFECHA (Holmes *et al.*, 1986) for possible measurement or dating errors. This involves statistical cross dating to test each individual series against a master chronology of the site on the basis of correlation coefficients. Any error in dating was rectified by re-checking/ re-measuring the sample. All chronologies showed good cross matching.

## CLIMATE DATA

The network of meteorological stations over western Himalaya is sparse and records are discontinuous. Particularly at higher elevations very few meteorological stations are available. Consequently, it is commonly difficult to locate meteorological stations close to the tree-ring sites for

| Site | Location | Elevation in Meter | Date of Collection | Species | Chronology name | No. of cores |
|---|---|---|---|---|---|---|
| Narkhanda (H.P.) | 31°12' N 77°14' E | 3000 | April, 1990 | *Abies pindrow* | NARAP | 12 |
| | | | | *Picea smithiana* | NARPS | 6 |
| | | | | *Cedrus deodara* | NARCD | 12 |
| Gahan (H.P.) | 31°11' N 77°14' E | 2500 | April, 1990 | *Picea smithiana* | GAHPS | 10 |
| Kufri (H.P.) | 31°07' N 77°10' E | 2600 | June, 1989 | *Cedrus deodara* | KUFCD | 15 |
| Kanasar (U.P.) | 30°45' N 77°48' E | 2200 | June, 1989 | *Cedrus deodara* | KANCD | 9 |
| Dhanolti (U.P.) | 30°45' N 78°25' E | 2400 | April, 1991 | *Picea smithiana* | DHAPS | 5 |
| Ghansali (U.P.) | 30°37' N 78°45' E | 2100 | April, 1991 | *Pinus roxburghii* | GHAPR | 12 |

Fig. 1—Western Himalayan tree-ring sites used for density measurement.

| Sr. No. | Station | State | Latitude | Longitude | Elevation(m) | Rainfall Period | Temperature Period |
|---|---|---|---|---|---|---|---|
| 1 | Srinagar | J & K | 34° 05' | 74° 50' | 1587 | 1893-1990 | 1893-1990 |
| 2 | Shimla | H.P. | 31° 06' | 77° 10' | 2202 | 1863-1990 | 1876-1990 |
| 3 | Mussoorie | U.P. | 30° 27' | 78° 05' | 2042 | 1869-1990 | 1901-1990 |
| 4 | Dehradun | U.P. | 30° 19' | 78° 02' | 682 | 1861-1990 | 1901-1990 |
| 5 | Pauri | U.P. | 30° 08' | 78° 55' | 1595 | 1871-1982 | — |
| 6 | Nainital | U.P. | 29° 24' | 79° 28' | 1953 | 1849-1982 | — |
| 7 | Mukteshwar | U.P. | 29° 28' | 79° 39' | 2311 | 1901-1990 | 1901-1990 |
| 8 | Almora | U.P. | 29° 35' | 79° 41' | 1676 | 1856-1982 | — |
| 9 | Joshimath | U.P | 30° 33' | 79° 34' | 1875 | 1871-1990 | — |
| 10 | Pithoragarh | U.P. | 29° 35' | 80° 15' | 1639 | 1864-1982 | — |

Fig. 2—List of meteorological stations of Western Himalaya used in the analysis.

dendroclimatic analysis. In the present analysis monthly rainfall and monthly mean surface temperature anomalies for the period AD 1901-90 were calculated from the data of the stations widely spread over the western Himalaya as listed in Fig. 2. These stations possess continuous data of monthly rainfall and temperature for the period as shown in Fig. 2. Most of the climate time series show significant correlations ($p < \cdot 001$) among the stations (Pant *et al.*, 1999). The regional anomalies have been obtained by arithmetic average of individual station's anomalies from their respective means. Thus, the monthly anomalies of rainfall based on the data of 10 stations and temperature anomalies based on data of 5 stations represent the climate of entire western Himalayan region. These anomaly series were used further in response function analysis for dendroclimatic modelling.

| Parameters | Chronology name | Common period | Mean sensitivity | Mean correlation between the trees | Signal to noise ratio (SNR) | % Variance due to first eigen vector | Expressed population signal (EPS) |
|---|---|---|---|---|---|---|---|
| Ring width | NARAP | 1749-1986 | ·23 | ·36 | 6·75 | 44 | ·87 |
| | NARPS | 1805-1988 | ·22 | ·33 | 2·95 | 46 | ·74 |
| | NARCD | 1835-1982 | ·25 | ·30 | 5·14 | 40 | ·84 |
| | GAHPS | 1857-1984 | ·22 | ·37 | 5·87 | 41 | ·86 |
| | KUFCD | 1899-1984 | ·23 | ·42 | 10·86 | 45 | ·91 |
| | KANCD | 1878-1986 | ·29 | ·38 | 5·52 | 46 | ·85 |
| | DHAPS | 1852-1988 | ·25 | ·37 | 2·93 | 40 | ·75 |
| | GHAPR | 1861-1982 | ·26 | ·31 | 5·39 | 42 | ·84 |
| Earlywood Density | NARAP | 1749-1986 | ·11 | ·32 | 5·65 | 42 | ·85 |
| | NARPS | 1805-1988 | ·08 | ·39 | 3·80 | 47 | ·79 |
| | NARCD | 1835-1982 | ·10 | ·28 | 4·67 | 38 | ·82 |
| | GAHPS | 1857-1984 | ·08 | ·39 | 6·39 | 40 | ·86 |
| | KUFCD | 1899-1984 | ·05 | ·28 | 5·83 | 36 | ·85 |
| | KANCD | 1878-1986 | ·07 | ·21 | 2·39 | 34 | ·70 |
| | DHAPS | 1852-1988 | ·05 | ·40 | 3·33 | 41 | ·77 |
| | GHAPR | 1861-1982 | ·05 | ·29 | 4·90 | 39 | ·83 |
| Latewood Density | NARAP | 1749-1986 | ·05 | ·05 | ·63 | 23 | ·39 |
| | NARPS | 1805-1988 | ·04 | ·05 | ·5 | 26 | ·24 |
| | NARCD | 1835-1982 | ·10 | ·09 | 1·18 | 20 | ·54 |
| | GAHPS | 1857-1984 | ·07 | ·11 | 1·23 | 25 | ·55 |
| | KUFCD | 1899-1984 | ·28 | ·23 | 4·48 | 29 | ·81 |
| | KANCD | 1878-1986 | ·03 | ·08 | ·78 | 22 | ·41 |
| | DHAPS | 1852-1988 | ·02 | ·12 | ·68 | 18 | ·40 |
| | GHAPR | 1861-1982 | ·04 | ·18 | 2·63 | 28 | ·72 |

Fig. 3—Statistics for residual chronologies of ring width and density parameters of western Himalayan conifers.

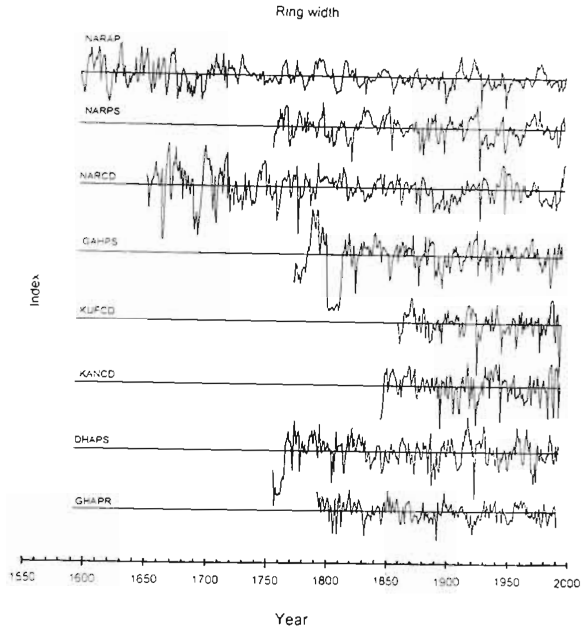


Fig. 4 (a)—Ring width index chronologies from western Himalaya.

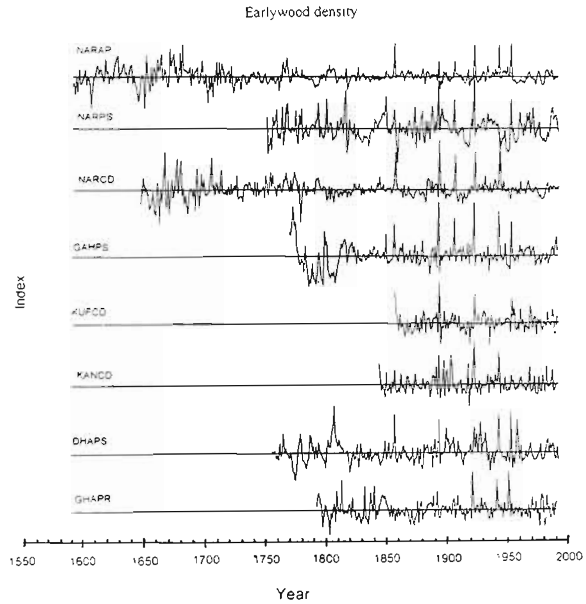


Fig. 4 (b)—Earlywood density index chronologies from western Himalaya.

## DENDROCLIMATIC ANALYSIS

Before using the tree-ring series for dendroclimatic modelling, they were standardised using computer programme ARSTAN (Holmes *et al*., 1986) to remove non-climatic signal and maximise common climatic signal in the series (Fritts, 1976; Cook *et al*., 1990). All series were standardised by applying a suitable spline as this option gives the optimum signal as demonstrated by Borgaonkar *et al.* (1999) for western Himalayan conifers. Most of the tree-ring series show many occasions of suppression and release of tree growth. This may be due to natural survival competition among the trees, hence cubic spline smoothing is more suitable than other filters, such as negative exponential, linear regression, polynomial etc. Exogenous disturbances (fire, insect, pollution) are less over the sites, therefore, the spline stiffness was selected as 60%N, where, N is series length (Cook *et al*., 1990; Borgaonkar, 1996). The programme ARSTAN also gives the information about dendroclimatic potential of the series in terms of common variance explained by the individual series, which is attributable to climate. Significant persistence (autocorrelation) in the series is a common feature of Himalayan conifers (Borgaonkar, 1996). The auto-regressive modelling option in the programme ARSTAN was used to remove autocorrelation structure from the series thus forming the residual version of the chronology.

Fig. 3 gives some important common period statistics for total ring width, minimum earlywood and maximum latewood densities of eight different residual chronologies. These statistics are informative to evaluate the dendroclimatic potential of the tree-ring series (Fritts, 1976). It was observed that ring-width chronologies exhibit moderately high values of mean sensitivity (the average relative difference from one ring to the next). Mean correlation between the trees and variance due to first eigen vector, which are the measure of common signal, are relatively higher in ring-width and earlywood density than latewood density chronologies. These high values may be due to a widespread common climate signal. The ring-width and earlywood density series also show large signal to noise ratio. This reveals that earlywood density of Himalayan conifers is climatically more sensitive than the latewood density. These results are similar to those presented by Pant *et al.* (2000) for density parameters of two *Cedrus deodara* sites of the western Himalaya. Fig. 4a and b represent residual chronologies of ring width and earlywood density respectively. The Expressed Population Signal (EPS) given in Fig. 3 quantifies the degree of which the sample size of particular chronology represents the hypothetically perfect chronology. The EPS values of ring-width and earlywood density chronologies are sufficiently high and statistically reliable for climate studies. (Briffa & Jones, 1990).

Response function analysis (Fritts, 1976) was used to study the tree growth -climate relationship. For this purpose, principal components of monthly mean surface temperature and precipitation anomalies of western Himalaya were used as predictor variables in multiple regression analysis (response

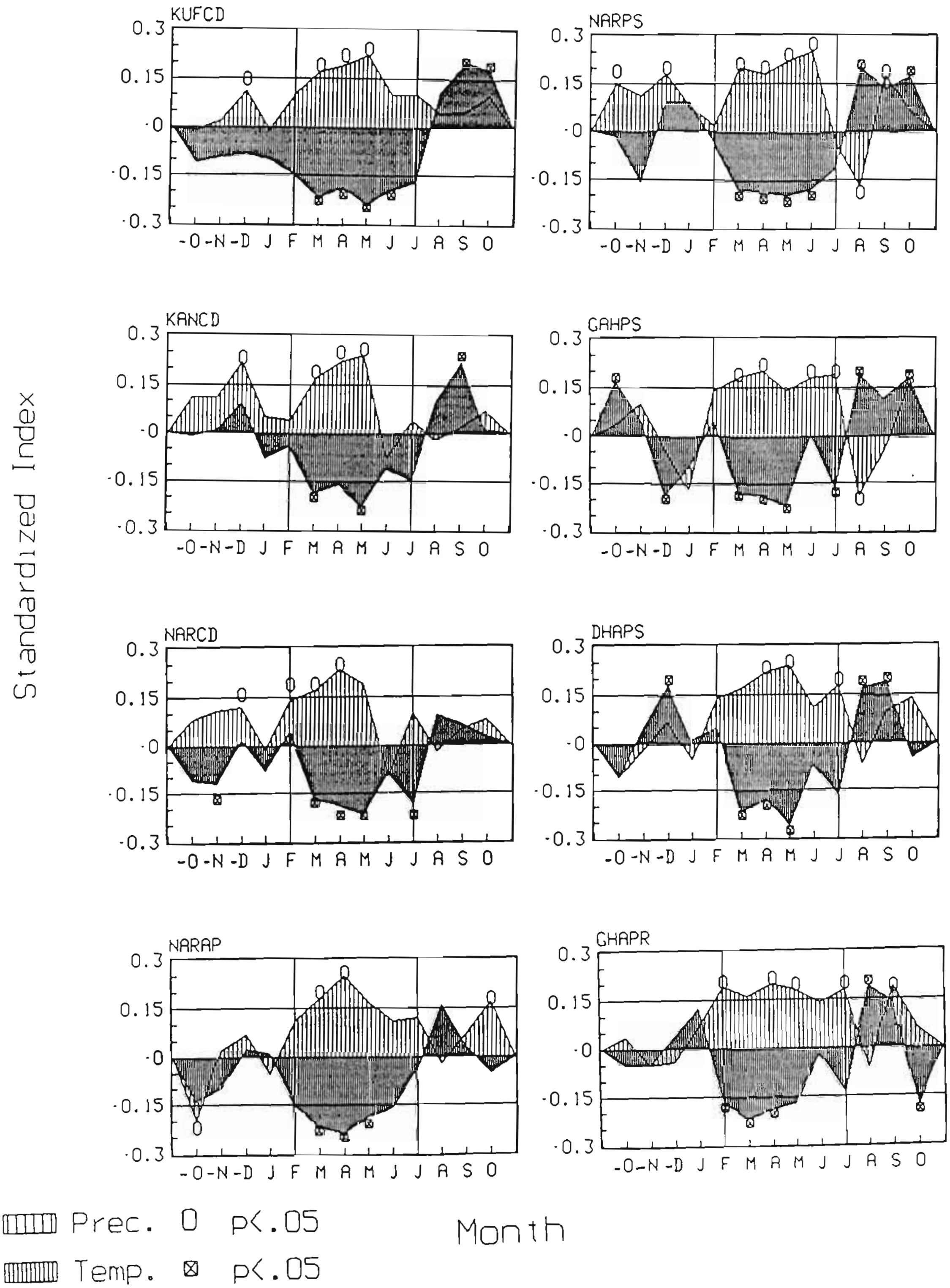


Fig. 5—Response functions of eight ring width chronologies calculated with monthly temperature and precipitation anomalies of western Himalaya. Crossed squares and circles indicate significance level at $p < \cdot 05$.

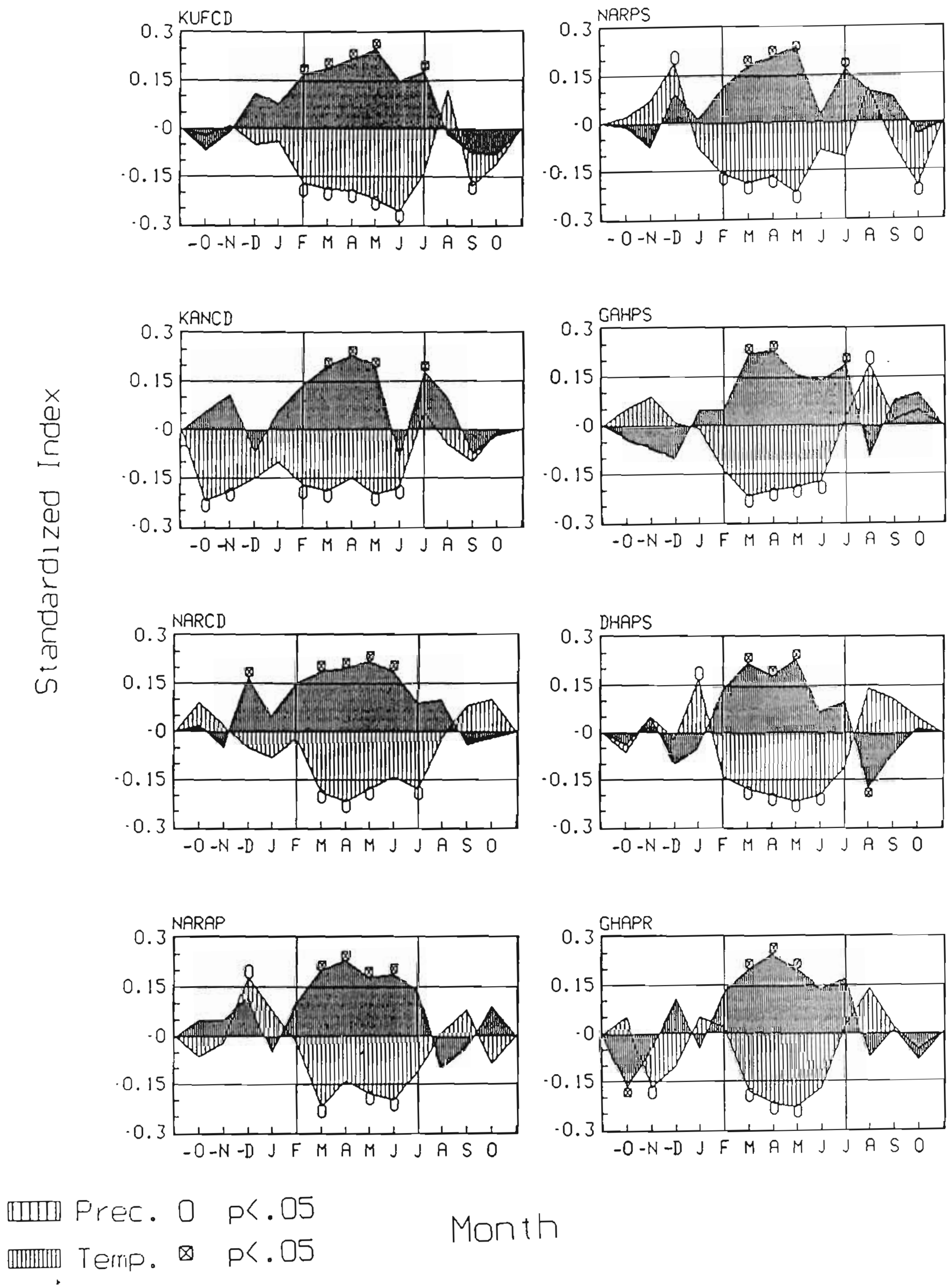


Fig. 6—Response functions of eight earlywood density chronologies calculated with monthly temperature and precipitation anomalies of western Himalaya. Crossed squares and circles indicate significance level at p < ·05.

function) to calculate the effect of each climate variable on tree growth parameters (total ring width and earlywood density). The active growth period of the Himalayan conifers is generally from March to October. Hence the climate variables were selected as previous October (end of prior year's growing season) to current October (end of current year's growing season) as discussed in detail by Borgaonkar (1996). Therefore, a total 26 climate variables, 13 each of temperature and precipitation anomalies for the period 1901-90 were used in the response functions analysis as predictors. The series of rainfall and temperature anomalies for the period 1901-90 were selected in response function analysis, as this period is common both in rainfall and temperature data and cover maximum number of stations. Response functions were constructed with residual chronologies of ring width and earlywood density of each site as predictands. Latewood density chronologies, which do not show any significant common signal related to climate (Fig. 3), were not used in the response function analysis. Calculations were done with Programme PRECON (Fritts, 1997). Figs. 5 and 6 represent the response function results of ring width and earlywood density, respectively, for all the site chronologies of western Himalaya.

It was observed that summer pre-monsoon (March-April-May) temperature and precipitation are the major parameters influencing on tree growth of the each site included in this analysis. Crossed squares and circles in Figs. 5 and 6 indicate the significant relationship at 95% confidence interval for temperature and precipitation respectively. In the case of ring width (Fig. 5), temperature in summer months, particularly in March-April-May shows significant negative relationships over all the tree-ring sites. Precipitation during same months indicates a significant positive relationship. In the case of earlywood density exactly the opposite pattern was observed for all the sites (Fig. 6). Summer temperature shows a significant positive relationship and precipitation shows a negative association. This is mainly because of moisture stress conditions (high temperature and low precipitation) occurring during the early growing season of the Himalayan conifers. However, latewood density parameters did not show significant relationship with the climate.

## DISCUSSION AND CONCLUSION

It was first observed by Pant *et al.* (2000) that earlywood density Himalayan Cedar (*Cedrus deodara*) are climatically more sensitive than latewood density in dendroclimatic reconstruction. Many other studies on sub-alpine conifers indicated a greater utility of maximum latewood density and ring-width than the minimum earlywood density in dendroclimatic reconstructions (Schweingruber *et al.*, 1978, 1979; Hughes *et al.*, 1994; Yasue *et al.*, 1997). Hughes (1992) also noted the maximum latewood density of *Abies pindraw* from Kashmir was greatly influenced by the summer temperature. In the present analysis, response of earlywood density and ring width of different conifer species from various parts of western Himalaya indicates strong association with pre-monsoon summer climate. Various statistical parameters of tree-ring chronologies in Fig. 3 also indicate higher dendroclimatic potential of earlywood density and ring width than the maximum latewood density.

The climate of Kashmir is different from the other parts of western Himalaya at lower latitudes including Himachal Pradesh and Uttaranchal. Kashmir is outside the monsoon currents and strongly influenced by extra-tropical western disturbances. Whereas, southern parts of western Himalaya experience moderate influence of monsoon precipitation. Over this part moisture stress condition occur in pre-monsoon months (March-April-May) when temperature is high and precipitation amount is very small (Borgaonkar, 1996). This period coincides with early growing period of the conifers. Hence earlywood density is influenced by the climate during this period. The similar climatic conditions (higher temperature and low precipitation) are observed in May-June-July over Kashmir region which influences later part of growing season of the conifers, hence, latewood density shows significant response to climate of these months as noted by Hughes (1992).

In response function analysis, both ring width and earlywood density show significant relationships with pre-monsoon summer temperature and precipitation. However, the pattern of relationship is exactly opposite in both the cases. Temperature of pre-monsoon months is negatively correlated with ring width and positively correlated with earlywood density. A similar opposite pattern was observed in case of precipitation. As discussed by Pant *et al.* (2000) this is mainly because water deficit in the early growing season suppresses rapid expansion of tracheids (Fritts, 1976). Tracheid diameter contributes to the density variations. Smaller diameter also contributes less ring width, as ring width is the sum of radial diameters of the tracheids. Trees produce narrower tracheids if water is less available. Water deficit in the growing season suppresses enlargement of tracheids. When tracheids become narrower, the proportion of cell wall increases due to the reduction of lumen size. Larger cell wall portion in earlywood gives higher value of density. This explains why narrow rings contribute high values of earlywood density. Xiong *et al.* (1998) also showed the high dendroclimatic potential of earlywood tree-ring parameters (earlywood width and density) of New Zealand pink pine (*Halocarpus biformis* Hook).

This clearly establishes the great performance of density parameters of Himalayan conifers in dendroclimatic studies and indicates that the use of earlywood density parameters jointly with ring width may provide a more robust picture of past climate over the entire western Himalaya than the available reconstructions obtained only with total ring width.

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