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Climate and Growth Relationship in Blue Pine (*Pinus wallichiana*) from the Western Himalaya, India

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인도 西히말리아産 블루파인(*Pinus wallichiana*)의 年輪生長과 氣候와의 關係

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ABSTRACT

Ring width chronologies of blue pine (*Pinus wallichiana*) from two mesic sites, Kanasar(2,400 m) and Gangotri(3,000 m), in the western Himalayan region, India were developed to understand tree growth-climate relationship and its applicability in proxy climate studies. The response function analyses of the two chronologies show that the site conditions play an important role in modulating the effect of climatic variables on tree growth.

Winter temperature, prior to the growth year, has been found to play positive influence on blue pine growth at both sites. Summer temperature also has very similar response except for June and August. June temperature has negative influence at the lower in contrary to at the higher site. Low August temperature favors tree growth at higher elevation but it has no significant influence at the lower site. Response of tree growth to precipitation has been found to vary which could be due to different precipitation regime at the two sites. Winter precipitation is important for tree growth at the higher, whereas summer at the lower site.

The present study suggests that the tree ring materials of blue pine from the temperate Himalayan regions could be used to develop chronologies for the reconstruction of seasonal climatic variables.

Key words: Blue pine, *Pinus wallichiana*, Ring rings, Western Himalaya, India.

INTRODUCTION

Several tropical and temperate tree species growing chiefly in areas with distinct climatic seasonality in India have well defined growth rings. Studies on dendrochronologically dated growth ring sequences in many of such trees by various workers (Pant 1983, Pant and Borgaonkar 1983, 1984a, Ramesh *et al.* 1985, Hughes and Davies 1987, Bhattacharyya *et al.* 1988, Yadav and Bhattacharyya 1992, 1994, Bhattacharyya and Yadav in press) have indicated that the tree ring chronologies provide valuable data base to supplement the meteorological records. The long term climate data series, derived from tree rings, will help in identifying the pre-industrial climatic variability and distinguish natural variations from anthropogenic ones. The longer records will also be very useful in the understanding of extraregional climatic coupling, sequence and phasing of major climatic conditions.

The climatic information contained in tree ring sequences of different species depends on their ecological requirements and climatic factors stressing the growth. Therefore, different environmental variables could be studied from the tree ring sequences of species growing in their respective habitats. For the reconstruction of climatic variables, especially precipitation and temperature, authors are developing network of different species chronologies from tropical and temperate regions of India. In sequel to this, tree ring analysis of blue pine (*Pinus wallichiana*) from two sites in the western Himalayan region was carried out and reported in the present paper.

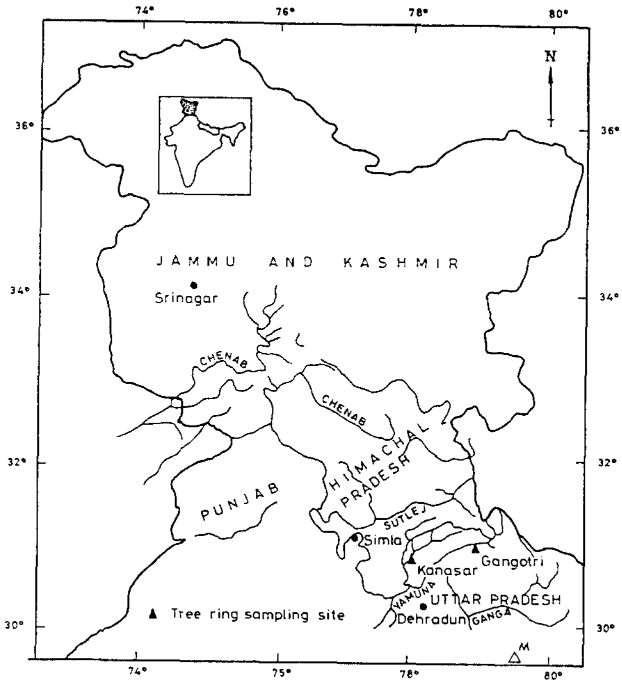

Fig. 1. Location map of the sampling sites (filled triangles). The meteorological station (M) is indicated by open triangle.

MATERIALS AND METHODS

Tree-ring materials

The blue pine is a large evergreen tree with its natural distribution all along the Himalaya from Pakistan to Arunachal Pradesh in India through Nepal and Bhutan at altitudes ranging from 1,800 ~3,900 m. It usually prefers to grow on deep moist soils, pure or mixed with Himalayan cedar (*Cedrus deodara*), spruce (*Picea smithiana*), fir (*Abies pindrow*) and oak (*Quercus semecarpifolia*). At higher elevations beyond 3,000 m, it is associated with birch (*Betula utilis*) and juniper (*Juniperus macropoda*).

Tree-ring samples for the present study were collected in the form of increment cores from two mesic temperate forest sites in the western Himalaya (Fig. 1). The site environments vary considerably at both the sites in terms of aspect and forest composition. The site at Kanasar (2,400 m, a.s.l.) has flat topography whereas at Gangotri (3,000 m, a.s.l.) with varying degree of slopes. The trees are much prone to tilting due to frequent rock falls in the latter site. The main associate of blue pine at Kanasar site is Himalayan cedar whereas spruce and fir at Gangotri. The site and trees were selected in order to avoid any visible disturbance. Two increment cores per tree were collected from ten mature trees from each site during March, 1989.

Dating and chronology preparation

Tree ring sequences of the increment cores were dated by employing crossmatching of the ring width sequences using skeleton plot method (Stokes and Smiley 1968). False rings were commonly noticed in samples during young tree ages but could easily be recognized by their anatomical feature. Missing rings were not found in any sample. Crossdated ring width sequences were measured using the ring width

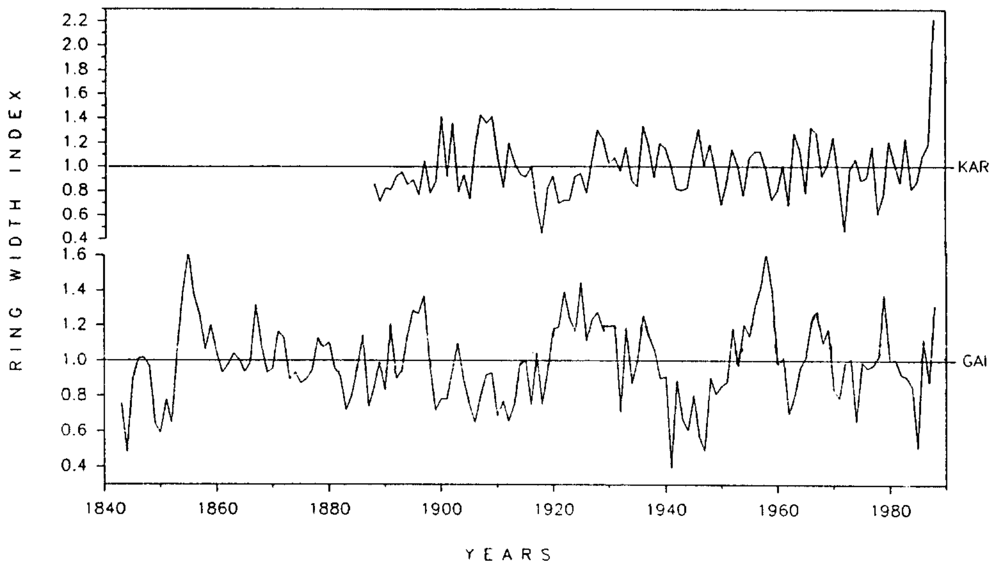

Fig. 2. Ring width chronologies of *Pinus wallichiana*.

Table 1. Chronology(ARSTAN) of *P. wallichiana*

Chronology	Trees(cores)	Span(years)	Median	Mean sensitivity	Skewness	Kurtosis	Autocorrelation order I
KAR	8(11)	1888~1988 (101)	0.955	0.229	1.388	5.615	0.204
GAI	9(10)	1843~1988 (146)	0.975	0.186	0.134	0.185	0.534

measuring machine with the accuracy of .01 mm. The ring width measurements were used to check the quality of crossdating by using the computer programme COFECHA (Holmes 1994). This programme helps in the identification of segments of a core or group of cores where dating problems might be present. The segments of samples where dating problems were indicated by this programme were rechecked under the microscope. Though skeleton-plots showed very good crossdating poor correlation was noted among many radii. This led to the rejection of many core samples. Finally we selected eleven cores from eight trees of Kanasar site and eight cores from eight trees of Gangotri site for chronology preparation.

The ring width measurement series of each well dated core was transformed to ring width indices by using programme ARSTAN (Cook 1985, Holmes 1994). Each sample series was double detrended by using negative exponential or linear-regression fits followed by cubic spline with 50% frequency response cut-off at 128 years wavelength (Cook 1985). The two site chronologies, Kanasar (KAR) 1888~1988 AD and Gangotri (GAI) 1843~1988 AD (Fig. 2) were computed by using biweight robust mean. The chronology statistics are shown in Table 1 and 2. The mean sensitivities, 0.229 and 0.186 of two chronologies, respectively, are low similar to the earlier chronology of this species developed from northwest Himalaya (Bhattacharyya *et al.* 1988). The first order autocorrelation in the chronology from

Table 2. Chronology common interval analysis

Chronology	Trees (cores)	Period (years)	Mean correlation among all radii	Signal / noise ratio
KAR	8(11)	1923~1987 (65)	0.371	4.720
GAI	8(8)	1887~1988 (102)	0.430	6.025

Kanasar is low in comparison to that of the Gangotri. The chronology common interval analysis shows good mean correlation between the trees from both the sites with signal-to-noise ratio 4.720 and 6.025 respectively. These features give a good guide to the potentiality of developing tree ring chronology of this species for palaeoclimatic studies in the Himalayan region.

Climate data

To understand the tree growth climate relationship, usually climate data of meteorological stations close to the sampling sites should be used. But in case of the Himalayan region, meteorological stations with long, continuous records are sparse and very seldom near to the good tree ring sites of natural, undisturbed forests. Due to the very practical reasons, the meteorological stations are to be located on accessible sites whereas the natural, undisturbed forests could be found far, in the interior sites, on up the mountains or down the valleys.

Nonetheless, there are some meteorological stations in the western Himalayan region with long continuous climate records. Pant and Borgaonkar(1984b) analysed the rainfall data of six such meteorological stations from the western Himalayan region and found that the data are correlated significantly at 1% level. This indicates that the meteorological data of stations located even at some distances from the tree ring sites could be used to calibrate tree growth climate relationship. For the present study, climate data from Mukteshwar(29°28′ N and 79°39′ E, 2,314 m, a.s.l.), around 100 km southeast of the sampling sites were used. Average monthly mean temperature and precipitation ranging through various months show that May and June are very warm whereas January and February cold(Fig. 3). The July and August are the wet months when monsoon rainfall occurs.

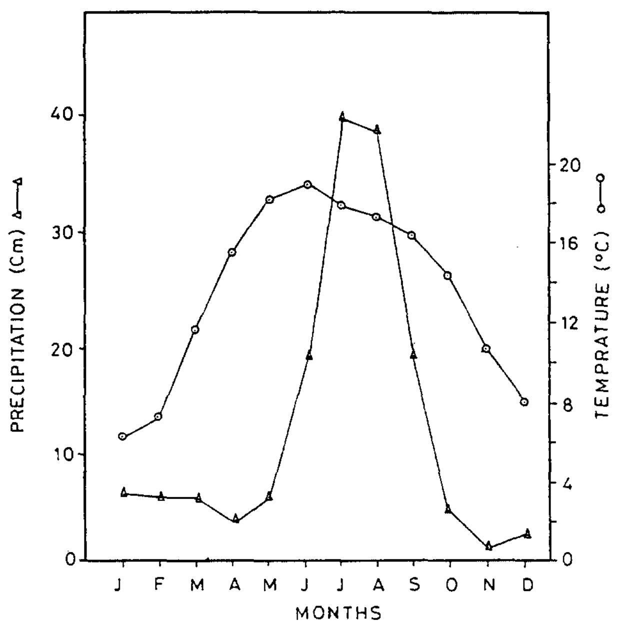

Fig. 3. Mean monthly temperature and precipitation for Mukteshwar meteorological station.

Tree growth-climate relationship

The response function analysis(Fritts 1976) was used to calculate tree growth-climate relationship. For this, each site was treated separately and the mean chronology was taken as the measure of tree growth at the site. Average monthly temperature and total monthly precipitation starting from October of the year preceeding growth to October of the current growth year were used.

Fifty years climate data(1939~1988) were taken for the response function analysis. The response functions showing the direction and magnitude of the effect of climatic variables on tree growth are shown in Fig. 4 and 5.

RESULTS AND DISCUSSION

Response function analysis with the KAR chronology has shown that winter temperature(December-February), prior to the growing season, is directly related with tree growth. Temperature of current year's May-June, which are usually hot and dry in this region, have negative effect. July temperature has positive influence on growth. The summer monsoon which lowers effective temperature usually arrives dur-

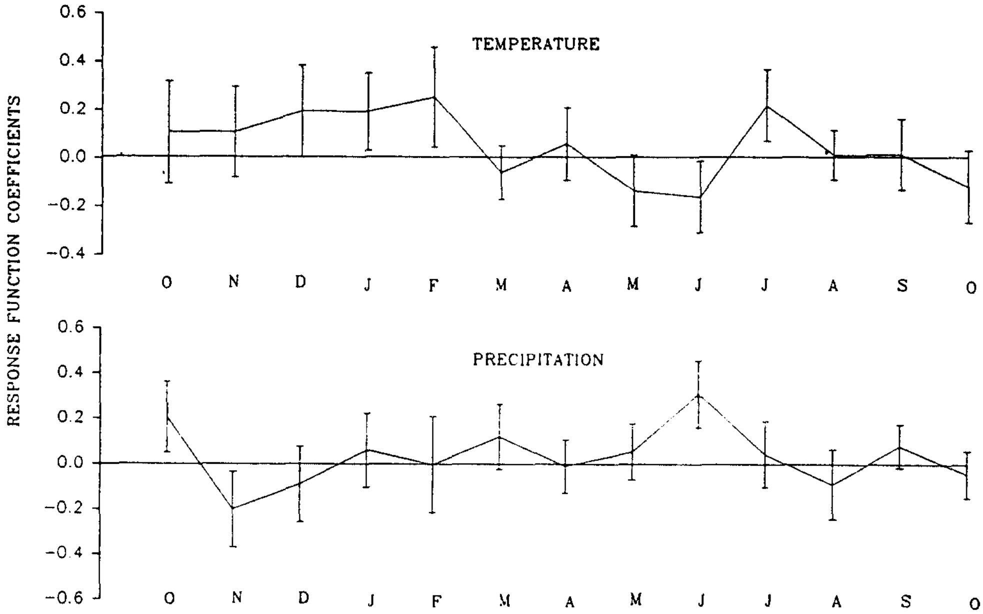

Fig. 4. Response function plots of Kanasar chronology with climate variables(mean monthly temperature and monthly precipitation) from October of prior growth year to current year's October, the vertical bars indicate 95% confidence limits.

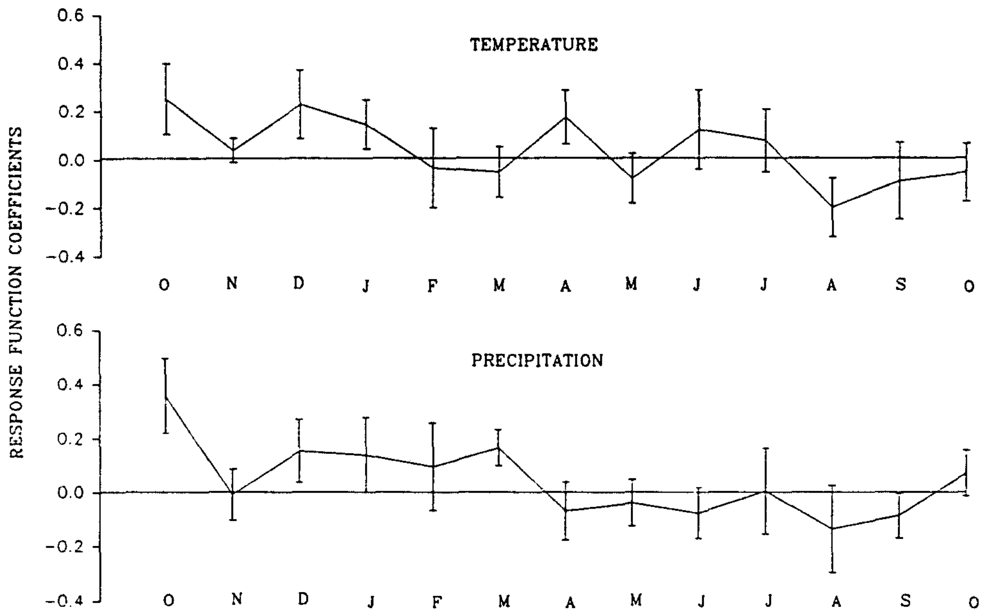

Fig. 5. Response function plots of Gangotri chronology with climate variables(mean monthly temperature and monthly precipitation) from October of prior growth year to current year's October, the vertical bars indicate 95% confidence limits.

ing this month. Therefore, when moisture supply becomes very high, higher temperature seems to favor the tree growth.

Precipitation of previous year's October and current year's June have shown direct relationship with tree growth. November precipitation has negative effect. Total climatic variance in the chronology has been found to be 50%.

The response function analysis with the GAI chronology, the site which is 600 m at higher elevation than the previous one, has indicated that the temperature of October and winter(December-January) prior to growth year have direct influence on growth. The temperature of April when the buds have been observed to sprout in this area, plays positive influence. August temperature has negative effect on tree growth.

The precipitation of previous year's October and December and current year's January and March have direct effect. However, monsoon precipitation does not seem to play an important role on tree growth in this area. The total climatic variance in the GAI chronology has been found to be 39%.

The comparative study of response functions of the two sites shows that the site conditions play an important role in influencing the growth response of trees to monthly climate variables. There has also been found to be distinct analogy in temperature effect except for the month of June which has negative influence on tree growth at lower site in contrary to higher site. This could be very reasonable as the summer is very hot and dry at lower site in comparison to that at higher site. Winter precipitation has significant importance for tree growth at higher site whereas summer at lower site. Mild and wet June favors tree growth at lower site.

The present study suggests that the tree ring materials of blue pine from the temperate Himalayan regions could be used to develop chronologies for the reconstruction of seasonal climatic variables. The tree core samples taken from trees growing on slopes from Gangotri showed poor crossdating even within the radii of the same tree. This could be due to growth response of trees to multiple tilting caused by frequent rock falls and land slides. Bhattacharyya *et al.*(1992) noted that poor crossdating in this species is probably due to the presence of high first order autocorrelation in the ring width series. Rule of largest possible sample strategy should be more appropriate for tree-ring analysis of this species.

The response function analysis of the two site chronologies has indicated that temperature plays an important role for the growth of blue pine in the mesic sites. Due to the presence of dominant temperature signal in blue pine chronologies Bhattacharyya and Yadav(in press) demonstrated its close relationship with glacier fluctuations. However, direct relationship between tree growth and winter temperature observed in the present study is difficult to explain at this moment.

Usually it has been found that in temperate regions winter temperature, when trees are dormant, is detrimental to growth because of the high respiratory loss of food reserves due to high temperature. But, in contrary, there are also reports that some conifers in the Northwest Pacific fix 30~65% of their annual total carbon during the dormant season(Emmingham and Waring 1977, Waring and Franklin 1979). Several studies described in Kramer and Kozlolowski (1979, pp. 186~187) also document the occurrence of photosynthesis at very low temperatures. It could be possible that blue pine also photosynthesizes efficiently at low temperature during winter. However, more studies are needed to endorse the present findings.

It has been found that the site conditions play important role in modulating the effect of climate on growth. Therefore, chronologies from identical site conditions should be used to prepare regional chronologies for macroclimatic studies. The long regional chronologies will provide valuable data base to study the pattern of climatic changes. Studies on instrumental climate data of India(Hingane *et al.* 1985, Thapliyal and Kulshrestha 1991, Srivastava *et al.* 1992) indicate that the land mass of India has warmed at the rate of 0.4℃ per century. The long term temperature reconstructions from tree rings will provide sound basis to understand if the current warming is the natural course or due to the greenhouse effect.

적 요

인도 西히말리아의 중습한 두 지역인 Kanasar(해발 2400 m)와 Gangotri(해발 3,000 m)産 블루파인(*Pinus wallichiana*)의 연륜폭과 기후와의 통계적 관계를 분석함으로써 이 수종의 연륜연대기를 고기후 추정에 이용할 수 있는지를 조사하였다.

生育前年度의 冬季기온이 두 지역에서 공통적으로 블루파인 연륜생장과 陽의 관계를 가졌다. 夏季기온은 6월과 8월을 제외하고는 두 지역에서 매우 유사한 관계를 가졌다. 6월 기온과는 低地(Kanasar)가 高地(Gangotri)에서 보다 陰의 관계를 보여주었다. 8월의 경우, 高地에서는 기온이 낮을수록 연륜생장이 증대되었으나 低地에서는 별 영향이 없었다. 강수량과의 관계는 서로 상이하였는데, 이는 두 지역에서의 降雨 樣態가 서로 다름을 나타낸다. 高地에서는 冬季降雨가 연륜생장에 중요한 역할을 하는 반면에, 低地에서는 夏季降雨가 중요하였다.

두 지역에서의 연륜연대기에 대한 반응함수를 분석한 결과, 수목생장에 미치는 기후인자가 고도에 따라 서로 차이가 있음을 알 수 있었다. 이 연구의 결과는 히말리아의 온대지역에 자라는 블루파인의 연륜연대기로부터 계절별로 서로 다른 기후인자를 복원할 수 있음을 제시해 준다.

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