RESEARCH REPORT

DENDROCHRONOLOGICAL RECONNAISSANCE OF THE CONIFERS OF NORTHWEST INDIA

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ABSTRACT

Tree-ring samples were collected from six coniferous species in the western Himalayan ranges during the summer of 1984 in order to evaluate their potential for use in dendroclimatic reconstructions. *Picea*, *Abies*, and *Pinus* spp. had previously been collected for ring widths and densitometric analysis by Hughes and co-workers on relatively mesic subalpine sites near the Vale of Kashmir. Our results support this earlier work in that ring-width series from these habitats are relatively complacent and contain little dendroclimatic information. Density and ring widths are largely temperature-dependent. However, our sampling included *Cedrus deodara* and *Pinus gerardiana* from lower altitudes in the dry inner valleys of the Pir Panjal Range, south of Kashmir. Both species exhibit great age, high mean sensitivity and good intra- and inter-specific crossdating, and yielded chronology statistics suggestive of a drought response. We strongly recommend that they receive high priority in future tree-ring research in northwest India.

INTRODUCTION

Early botanists and foresters of India were well aware of the formation of annual growth rings in many Indian trees and their broad relationship with climate, and potential application in determination of age, growth rates and for identification of many taxa (Gamble 1982; Chowdury 1934, 1939, 1940a, 1940b and 1964). However, little tree-ring research has been carried out in the subcontinent of India. Modern tree-ring research began only toward the end of the 1970's based on annual ring-width data (Pant 1979, 1983), on stable isotope variations (Ramesh et al. 1985), and both annual ring-width and x-ray densitometric data (Hughes and Davies 1987). The Himalayan region presents the greatest immediate potential for tree-ring research because it contains many conifers with close affinities to species from Europe and North America that are already familiar to western dendrochronologists. Subhumid plant communities are comparable to some of the drier sites of the southwestern United States which have yielded drought-sensitive tree-ring series for climatic reconstruction. High priority must be given to the sampling of drought-sensitive trees from drier sites of the Himalayan region. The use of tree rings as proxy climate indicators would provide data for long-term climatic reconstruction could be applied to the study of climatic variability and, in particular, the behavior of the summer monsoon during the last few hundred years. In 1980 and 1982, M. K. Hughes (then Liverpool Polytechnic, now Laboratory of Tree-Ring

Research) in collaboration with R. Ramash (Physical Research Laboratory, Ahmedabad, India) made exploratory collections in the western Himalaya. Their intensive sampling was conducted at 14 sites in the subalpine forests around the Vale of Kashmir and from sites in Uttar Pradesh Himalaya and Himachal Pradesh. Hughes and Davies (1987) made well replicated site chronologies based on both densitometric properties and ring widths of *Abies pindrow* and *Picea smithiana* from the Vale of Kashmir.

CLIMATE

The climate of the northwest Himalaya region is diversified due to the great range in elevation and aspect. It varies from dry-hot to subhumid tropical conditions in the southern foothill region to temperate-cold and alpine in the northern and eastern mountains. The highest monthly temperatures generally occur in June over large areas, except in the Kashmir region where they occur during July. After this, temperature generally declines and minimum temperatures are recorded during January. The available temperature records from some meteorological stations of this region show that the minimum January temperatures range from 17°C at Drass in the Ladakh region to 14°C in Jammu (both are in Jammu and Kashmir State) and 1 °C in Simla, the capital of Himachal Pradesh. Precipitation occurs both in the form of snow and rain brought by the summer monsoon as well as by the western disturbances. In general the rainfall increases within northwest India because of the orographic effect of the foothills and outer Himalayan ranges. Many sites receive very little precipitation due to the rain shadow effect of the mountain ranges. The rainfall distribution in the region varies from 5 cm at Gilgit, 8 cm in Ladakh, 50 cm in Lahul Spiti, 115 cm in Jammu to over 340 cm in Dharam Shala in Himachal Pradesh. Most of the region receives maximum annual precipitation brought by the summer monsoon (generally from the first week of July to the middle of September). Kashmir, Ladakh, and Lahul Spiti receive precipitation mainly due to western disturbances during December to March.

TOPOGRAPHY

In the south, this region is veiled from the Punjab plains by the Siwalik hills and to the north by the Great Karakorum Range (Figure 1). Between these two lie, successively, the Lesser Himalaya, Great Himalayan Range, the Zanskar Range and the Ladakh Range of the Tibetan Himalayan. These ranges extend in a northwest-southeast direction and are characterized by rugged terrains, lofty peaks, and deep canyons. The Great Himalaya runs unbroken from about 35°N, 74°E, southeastwards to 28°N, 87°E and then eastward to 25.5°N and 95°E. The peaks of this range often reach above 6000 meters. To the south, the Lesser Himalaya ranges range in height between 2000 m and 4000 m while even farther south, the Siwaliks are not more than 2000 m in height. The Pir Pangal, the largest of the lesser Himalayan ranges, bifurcates from the Greater Himalayan region. The Vale of Kashmir lies between the Pir Panjal and the Greater Himalayan Range. The Zanskar Range occupies the area between Chandra River in the south and the Indus River in the north. The range, with a succession of peaks above 6000 m, extends southeastwards to the great peak of Kamet (7634 m) in the vicinity of Badrinath. The Ladakh Range or the Trans-Himalayan Range situated north of the Zanskar Range and across the Indus River forms the principal geographic feature of Ladakh, which extends from the Nanga Parbat area. The Great Karakorum Range is situated across the river Shyok which forms the northern boundary of the Ladakh and Pangong Ranges. It culminates at the right angle bend of the Shyok

River near the Shyok village. This range includes some of the world's highest peaks (K-2, Sushorbram, Masharbram, SaserKangri) and has some of the world's most extensive nonpolar glaciers (Siachen, Biafo, Baltoro, and Rimo).

VEGETATION

The northwest Himalaya exhibits greatly diversified vegetation types due to its great diversity in physiography, altitude, climate, and bedrock geology. The region is also affected by increasing anthropogenic activity. The vegetation ranges from alpine, subalpine, to temperate, grading from higher elevations to the subtropical and tropical at lower elevations. The vegetation (especially in terms of local flora) of this region has been studied by many workers. The present brief account on vegetation from our study area is based on information from Champion and Seth (1968).

The subtropical pine forests (*Pinus roxburghii*) generally occur up to 1220 m, but at some sites it extends to over 2000 m on exposed, dry south-facing slopes and well drained areas. At some sites the upper limit of these forests merges into *oak-rhododendron* plant communities which extend up to 1500 meters with the increasing availability of moisture on north-facing slopes. *Subtropical forest* merges with *temperate forests* at its upper limit. The distribution of taxa in the temperate forest mainly depends on altitude, aspect and precipitation. The moist temperate forest occurs at some sites at an elevation of about 1500 to 3000 m with rainfall about 1000-2500 mm. Most of this precipitation is brought by the southwest monsoon during July through September. Little is due to northwest disturbances during winter. Minimum temperatures occur in January, ranging from -3 to 2°C whereas maximum temperatures during August is 22 to 31°C. Conifers are the major elements but they are associated with some broad-leaf taxa. They generally prefer northern aspects whereas the broad-leaf vegetation is mainly confined to southern aspects. *Pinus wallichiana*, *Cedrus deodara*, *Taxus baccata*, *Picea smithiana*, *Abies spectabilis*, and *Abies pindrow* are

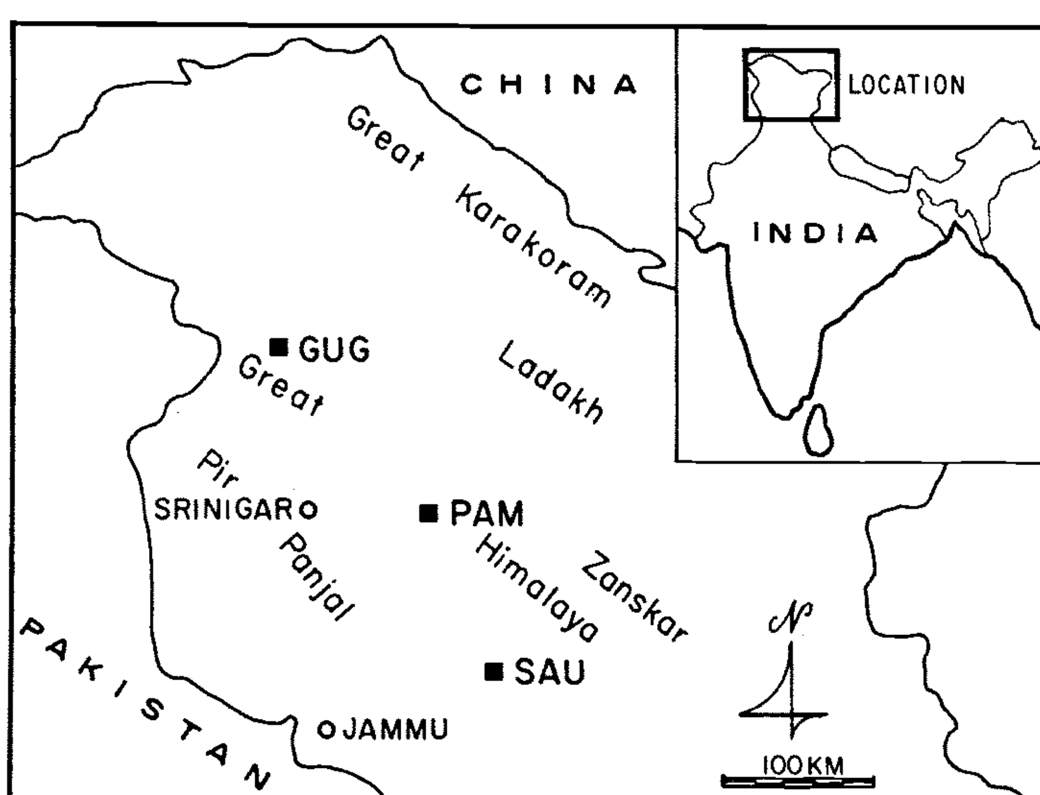

Figure 1. Location of tree-ring sites in relation to major mountain ranges, Jammu and Kashmir province, India.

conifer species associated with broad-leaf taxa represented by *Quercus*, *Rhododendron*, *Acer*, *Corylus*, *Aesculus*, and *Beluta*. Generally *Abies spectabilis*, *Quercus semecarpifolia*, and *Betula utilis* form the upper limit of this forest. *Dry temperate forest* occurs in the inner ranges, where most of the precipitation comes in the form of snow during winter and the effect of summer monsoon is limited. The mean annual precipitation is generally below 1000 mm. *Pinus gerardiana* and *Cedrus deodara*, with *Quercus ilex* and *Juniperus macropoda*, occur here at lower elevation and *Abies pindrow* with *Pinus wallichiana* grows at the upper elevation.

STUDY AREA

Our study sites represent three types of forests described above which occur over pronounced mesoclimatic gradients. They comprise subalpine humid conifer forests of *Picea smithiana* at Pahlgam (3402 m) and *Pinus wallichiana* with *Abies pindrow* at Gulmarg (3505 m), both in the vale of Kashmir, to the lower elevation of subhumid mixed temperate conifer forests of *Pinus wallichiana*, *Abies pindrow*, *Picea smithiana*, and *Cedrus deodara* at Kistwar (1500 m) and with increasing aridity gradually merges into 'subtropical *Pinus roxburghii* and ultimately to *Pinus gerardiana*, *Cedrus deodara*, and *Quercus ilex* plant community at Sashu (1800 m) (Figure 2). We emphasised collection of tree cores from *Pinus gerardiana* and *Cedrus deodara* growing in inner dry valleys of the northwest Himalaya. The potential exists for longevity in these trees based on published information. These trees generally attain a great girth (*Pinus gerardiana* 2-4 m and *Cedrus deodara* 9-11 m) with a moderate rate of growth (5 rings/cm). For example, a *Cedrus* tree growing at Kunwar has

Figure 2. *Pinus gerardiana* woodland, Sashu site.

Table 1. Sample statistics. Values in brackets are considered unreliable because of small sample size.

Chronology Identification	Number Trees	Number Radii	Period	Analysis of Variance
				%Y
PAMBC9	3	6	1900-1983	(8)
GUG9	6	12	1880-1983	11
SAU9	6	12	1904-1974	28

	Average Cross-Correlation Coefficients		
	Radii Within Trees	Radii Between Trees	Between Tree Means
PAMBC9	0.46	0.21	0.18
GUG9	0.50	0.14	0.19
SAU9	0.49	0.28	0.39

900 growth rings and a section of wood kept in the Forest Research Institute at Dehra Dun has 665 annual rings (Gamble 1902). Both *Pinus gerardiana* and *Cedrus deodara* are suitable for preparing long drought sensitive tree-ring chronologies from this region. Cores were collected from 10 trees of which three were *Cedrus deodara* and the rest from *Pinus gerardiana* growing around Sashu. Long cores could not be obtained from three trees of *Pinus gerardiana* due to the presence of heart rot. *Pinus wallichiana*, *Picea smithiana*, *Abies pindrow*, and *Cedrus deodara* from Kishtwar, and from the subalpine forests of Gulmarg (*Pinus wallichiana* and *Abies pindrow*) and Pahlgam (*Picea smithiana*) were also sampled for preliminary comparative analysis of tree-ring chronologies from trees growing under diversified habitat (Table 2). In this paper the dendrochronological potential of two species (*Cedrus deodara* and *Pinus gerardiana*) growing in inner valleys of the northwest Himalaya will be discussed at greater length.

SAMPLING AND DATING

Tree cores analyzed in this study were collected during our visit to India from 30 June to 30 July 1984 in connection with the Indo-USA monsoon research program. The amount of time for field collection was limited by the nature of the trip. However, we were able to obtain at least reconnaissance tree-ring collections from several coniferous species in two contrasting areas in Jammu-Kashmir, including the first collection from *Pinus gerardiana*. This is a first attempt to develop a long chronology from a new species growing under stress conditions. Tree-ring sequences of both *Cedrus deodara* and *Pinus gerardiana* were crossdated through the skeleton plot method (Stokes and Smiley 1968). Crossdating was noticed among all cores of individual species and between these two species. Both species contain some locally missing rings, but double rings are rare. The occurrence of missing rings is more prevalent in *Pinus gerardiana* than *Cedrus deodara.* Some cores collected from *Pinus gerardiana* were impossible to date due to the apparent absence of many rings.

ANALYSIS

After dating was completed, the ring widths in each dated core were measured to the nearest 0.01 mm using standard procedures followed in the Laboratory of Tree-Ring Research in Tucson, Arizona. The ring-width series of each core was then transformed to indices using the standard program INDEX developed by the Tree-Ring Laboratory (Graybill 1979). Most of the cores were standardized by using negative exponential or straight-line curves. Negative exponential curves were used where visible growth trend was seen in early part of the cores, whereas a horizontal line fitted through the mean of a series was used in the outer parts of *Cedrus deodara* where no visible growth trend is present. After standardization, the indices of each species were averaged for the cores from each tree and then averaged for all trees in the site to make a chronology for the species (Figure 3). We have combined the chronologies from *Cedrus deodara* and *Pinus gerardiana* to make a composite chronology for this site. This was done because the individual sample number for both species was small. The combining of chronologies of these two species was also justified as tree-ring sequences in both species show a good crossdating and also have more or less common chronology statistics. The chronology statistics for both species is shown in Table 3. In the subsequent steps, the analysis of variance and cross correlation analysis were obtained using computer program SUMAC (Graybill 1979) to judge the suitability and potential of average and individual tree-ring indices.

DISCUSSION AND CONCLUSIONS

In the analysis of variance (Table 1) the observed common variance among all trees considered to be due to climatic signal is about 28% (%Y), the remaining 72% is considered 'noise.' The climatic signal observed in our pine-Himalayan cedar chronology is much lower in comparison to the climatic signal present in trees growing in semiarid sites of western United States which may be due in part to the small sample size. The present pine-cedar chronology from Sashu showed a high climatic signal in comparison to other tree-ring chronologies so far studied from the Indian Subcontinent using tree-ring width data. A cross correlation analysis (Table 1) among tree-ring indices using common period 1904 to 1974 shows that there is a moderate correlation among all trees used in the site chronology. We hope by increasing our sample size it would be possible to enhance correlation among cores and the common climatic signal.

The potential exists to develop long chronologies from both *Cedrus* and *Pinus gerardiana.* In this study, one *Cedrus* tree was dated over 500 years without reaching the pith. We observed many stumps of logged *Cedrus* of about one foot height still *in situ.* These stumps may provide samples to develop a longer chronology from this site. A long chronology from *Pinus gerardiana* can also be made from this site. The trees were dated between 300 to 400 years, despite the presence of butt rot. Our present study shows that a drought sensitive chronology over 500 years could be developed from both *Cedrus deodara* and *Pinus gerardiana* in this region.

Dry temperate or subtropical forests of *Pinus gerardiana* and *Cedrus deodara* in many inner arid valleys of the western Himalaya would be suitable sites to collect samples. Besides

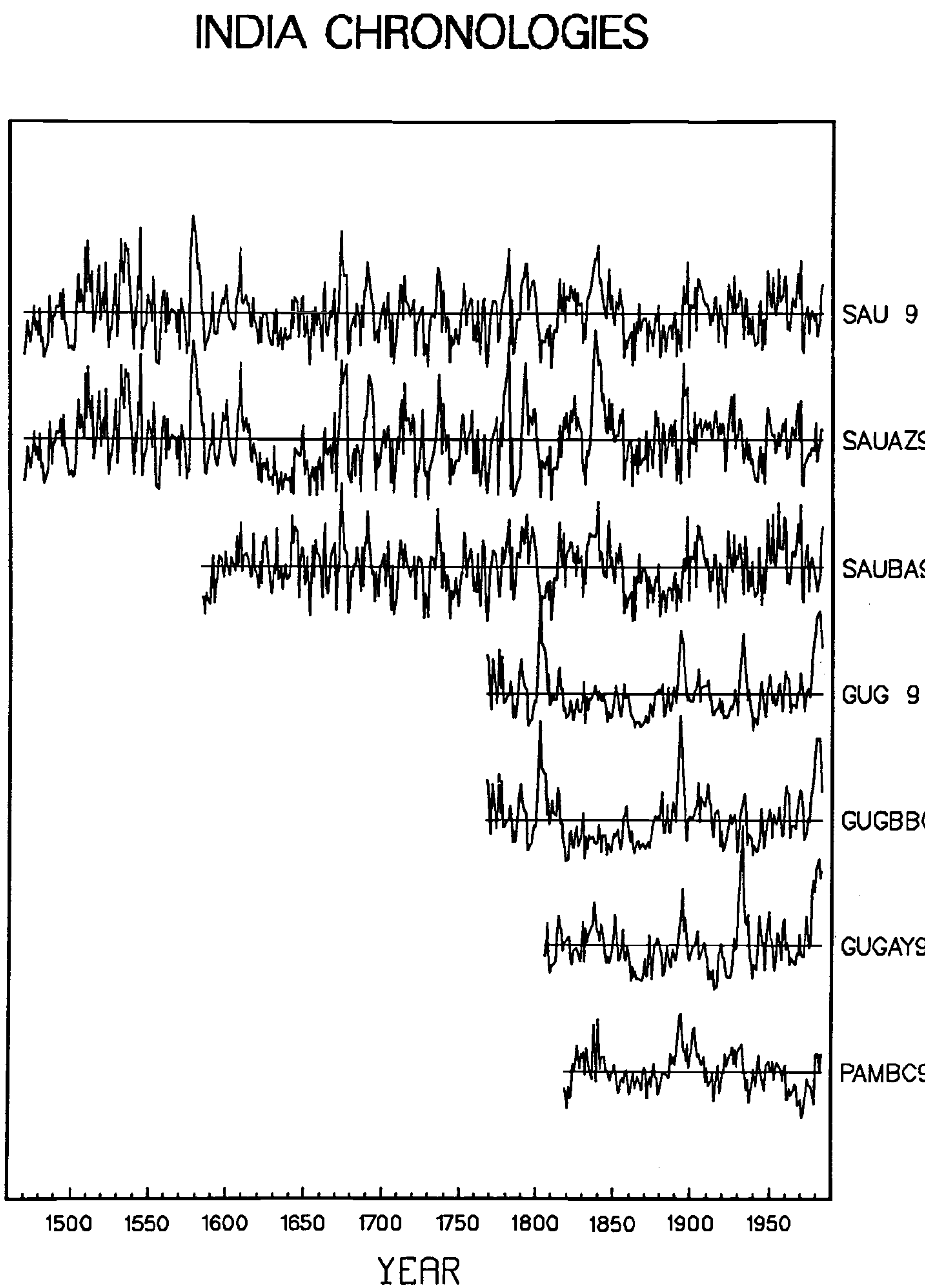

Figure 3. Ring-width index chronologies from India; SAU9 is a composite of SAUAZ9 and SAUBA9, GUG9 is a composite of GUGBBO and GUGAY9.

Table 2. Site Characteristics

Location	Species	Altitude (meters)	Latitude	Longitude	Slope (degrees)	Aspect	No. of Trees	Number of Radii	Abbreviation
Pahlgam	*Picea smithiana*	2620	34°42'E	75°42'N	3	N	3	7	PAM
Gulmarg	*Abies pindrow*	2740	35°05'E	74°18'N	25	S	3	8	GUG
	Pinus wallichiana	"	"	"	"	"	4	8	GUG
Sashu	*Pinus gerardiana*	1680	33°15'E	76°10'N	35	N	5	16	SAU
(Bagnic)		to	to	to	to	to	to		
	Cedrus deodara	1800	33°20'E	76°05'N	40	NE	3	10	SAU

Table 3. Chronology Characteristics

Chronology Identification	Species	Period (A.D.)	Mean Sensitivity	Standard Deviation	First Order Auto correlation	Percent Absent Rings
PAMBC9	*Picea smithiana*	1819-1983	0.19	0.29	0.64	0.22
GUGAY9	*Abies pindrow*	1805-1983	0.21	0.40	0.73	0.00
GUGBB0	*Pinus wallichiana*	1767-1983	0.22	0.41	0.74	0.00
GUG9	*Abies* plus *Pinus*	1767-1983	0.18	0.36	0.74	0.00
SAUBA9	*Pinus gerardiana*	1583-1983	0.37	0.39	0.42	2.66
SAUAZ9	*Cedrus deodar*	1469-1983	0.41	0.49	0.57	0.97
SAU9	*Pinus* plus *Cedrus*	1469-1983	0.36	0.42	0.49	2.05

Sashu and its adjoining region around Kishtwar in Jammu and Kashmir State, this pine-Himalayan cedar plant community also grows in inner valleys of Kinnaur and Panji division of Himachal Pradesh and extends to the adjoining region of Pakistan and Afghanistan. *Pinus roxburghii*, another promising dendroclimatological tree, is also found in this region. It grows in the areas which are comparatively less arid than sites growing with *Pinus gerardiana* and *Cedrus deodara*. Furthermore it occurs in a region where the main source of precipitation is the summer monsoon rather than winter precipitation. The potential of this species for dendroclimatological studies from the Indian subcontinent has already been proved from some sites in the western and central Himalaya. It has clear growth rings that can be easily crossdated, moderate mean sensitivity, a good percentage of common variance among trees and low first order of correlation (Pant 1983). However, the problem of finding old trees in most of the stands decreases the potential for long chronology development. The careful selection of sites, especially from the areas where this tree is growing under stress conditions and exhibits stunted growth and heavy old branches, may provide trees with sufficient age.

All the other conifers we sampled (*Abies Pindrow*, *Abies spectabilis*, *Juniperus communis*, *Picea smithiana*, *Taxus baccata*, *Pinus wallichiana*, and also *Cedrus deodara*) at higher elevations in temperate and subalpine forests provide datable annual ring sequences. As different species respond to the seasonal variability of climate in different ways, the growth-climate relationship from these species would be very useful to provide proxy climatic data to reconstruct various aspects of past climatic variability. So far, tree-ring chronologies have been developed from *Abies pindrow*, *Picea smithiana*, and *Pinus wallichiana* growing around Kashmir Valley (Hughes and Davies 1987, Ramesh et al. 1985) and around Kishtwar in Jammu and Kashmir State. A temperature reconstruction from 1890 to 1980 has been made for the Vale of Kashmir using densitometry and ring widths from *Abies pindrow* (Hughes and Davies 1987). Earlier Ramesh et al. (1985) also found that *Abies pindrow* and *Pinus wallichiana* would be suitable for dendroclimatological analysis using isotopic properties of tree rings. However, most of the tree-ring series are not long enough to make long replicated chronologies from this region.

Our present study consisted of a few trees of Himalayan cedar (*Cedrus deodara*) and Chilgoza pine (*Pinus gerardiana*) growing at Sashu near Kishtwar in Jammu and Kashmir State. It reveals that these trees are suitable for tree-ring analysis which will provide dendroclimatological information in India. They exhibit comparatively higher mean sensitivity, higher common variances among trees, and lower first order autocorrelation than other conifer species so far studied from the Indian subcontinent. However, this could be an artifact of sample size. A preliminary matching between tree-ring indices from these species with historical drought years from India, and mean precipitation from this region shows that low indices match drought years and low precipitation years indicating the potential of this site for reconstruction of past climatic variability.

Climatic reconstructions for the recent past from this region will be significant in developing an understanding of climatic variability in Southeast Asia. The bordering Tibetan Plateau has a great effect on the weather regimes of the Indian subcontinent in different months. It is now known that the Tibetan Plateau with an elevation of about 5 kilometers plays a significant role in changing the pressure gradient which regulates the monsoon climatic regime in Indian subcontinent. Climate oriented tree-ring research for the Tibetan Plateau is also now in progress at the Institute of Geography, Academia Sinica, Peking (Wu Xiangding, personal communication 1986). A large network of tree-ring climatic studies from both regions would help us better understand the variability in summer monsoon as well as precipitation brought by the western disturbances to the vast area of the northwestern part of the Indian subcontinent during winter.

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