47. Bhattacharya, A., Mondal, S. and Mandal, S., *Sci. Cult.*, 1997, **63**, 143–144.
48. Rana, A., Singh, J. and Chauhan, S. V. S., *Int. J. Mendel.*, 1996, **13**, 15–16.
49. Heslop-Harrison, J., Heslop-Harrison, Y. and Barber, J., *Proc. R. Soc. London*, 1975, **188**, 287–297.

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Tree ring analysis of *Larix griffithiana* from the Eastern Himalayas in the reconstruction of past temperature

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Tree ring analysis of *Larix griffithiana* (Lindl. et Gord.) Hort ex Carr., a subalpine deciduous conifer growing in Sange, Arunachal Pradesh, Eastern Himalaya has been taken up to understand past climatic changes of this region. Rings in this tree have been found very distinct, with clear demarcation of early wood and late wood cells and have characters suitable for dendroclimatic studies. Analysis of tree growth and records of climatic parameters suggest that May temperature is the most important factor in controlling growth of this tree. Reconstruction of May temperature using ring width data of this tree has been done.

THE available high-resolution climatic data from the eastern part of the Himalaya is limited. Tree ring proxy record seems to hold excellent potential to extend back the existing meteorological records of this region. History of tree ring analysis in the Indian subcontinent, especially from the western and central part of the Himalayan region has been reviewed recently[1]. Being under the influence of pronounced precipitation almost throughout the year, with varying intensity, this region is somewhat problematic for such studies. Under such climatic conditions, trees are expected to have false or multiple rings. However, recent exploratory studies[2–3] from this region have indicated several suitable trees and sites. It is a report on the prospect of reconstruction of past temperature using tree ring width data of *Larix griffithiana* from the Eastern Himalayan region.

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L. griffithiana (*LAGR*), a deciduous conifer is distributed at altitudes 2,400–3,650 m. Its provenance is from eastern Nepal, extending through Darjeeling, Sikkim, Bhutan and Arunachal Pradesh and continues up to NE upper Burma and Chumbi Valley in Tibet[4]. It grows up to 15–18 m in height with long pendulous branchlets and mostly occupies steep slopes on morainic deposits where drainage is good. The trees occur mostly in patches, either forming pure forest or more often mixed with other conifers.

Tree ring samples in the form of increment cores were collected from *LAGR* growing in Sange, West Kameng, Arunachal Pradesh (Figure 1). This site is characterized by very open mixed conifer forest. Trees are tall and straight with medium-sized girth (Figure 2). Associated species are mostly silver fir and *Rhododendron*. Undergrowth is rich and represented by bamboo, fern, etc. Soil cover is thin, but thick leaf cover and moss are present on the ground forming a mat. Twenty increment cores were collected from 11 trees growing on the southern slope of the hill at an altitude of 3320 m. In most cases two cores per tree, one each from the opposite directions at breast height were collected. In at least two cases, only one core could be collected, as the other side was not approachable due to steep slope. Samples were mounted and processed using standard procedure of tree ring analysis. Details of the methods of tree ring analysis can be found in several publications[5–7].

Boundaries of rings in *LAGR* tree are very sharp and there is a clear demarcation of early wood and late wood (Figure 3). Each ring of the cores was dated to the calendar year of its formation using cross-dating technique[8]. Ring width of each dated core was measured by

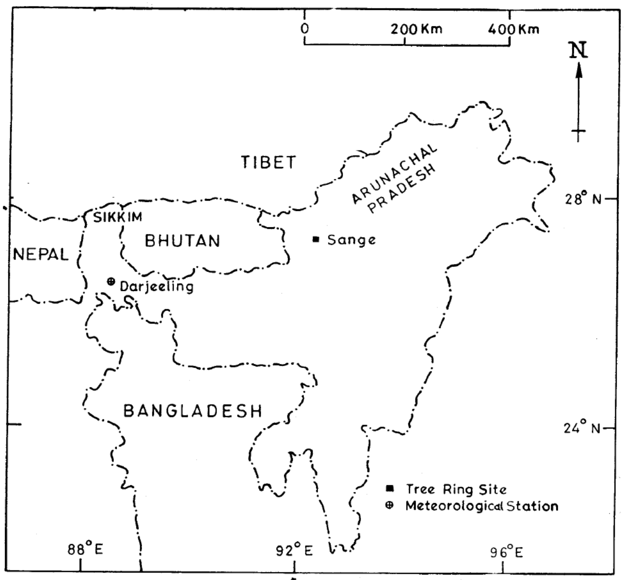

Figure 1. Location of tree ring site and meteorological station.

Figure 2. Photograph showing forest of *LAGR* at Sange, west Kameng District, Arunachal Pradesh.

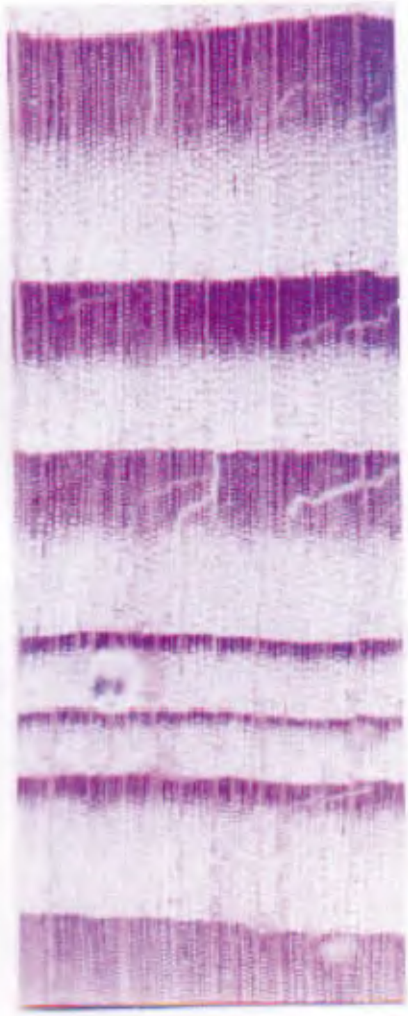

Figure 3. Anatomical features of *LAGR* showing clear demarcation of early wood and late wood within a ring.

Table 1. Statistics of ring width chronology of *LAGR*

Chronology time span	1891–1996
Mean sensitivity	0.14
Standard deviation	0.19
Lag-1 auto correlation	0.443
Common period (no. of cores/tree)	1926–1995 (16/11)
Correlation between trees	0.334
Correlation within trees	0.362
Signal to noise ratio	5.52
Expressed population signal	0.866
Variance in 1st eigen vector	39.13%

the increment-measuring stage coupled with a micro-computer with 0.01 mm accuracy. It was checked using a computer program COFECHA[9], which performs data quality control by thoroughly checking the tree ring measurements and locating all portions within a tree ring series showing weak or erroneous cross dating or measurement errors. The cores having errors were re-

Table 2. Summary of calibration results for different temperature averages using *LAGR* chronology

Predictand: Darjeeling temperature
Calibration: 1891–1920
Verification: 1921–1978

Season	Model	Calibration R^2	Verification R^2
May	t	0.168	0.193
	$t, t+1$	0.165	0.208
	$t-1, t$	0.180	0.226
July	t	0.002	0.002
	$t, t+1$	0.023	0.008
	$t-1, t$	0.004	0.089
May–July	t	0.068	0.089
	$t, t+1$	0.085	0.096
	$t-1, t$	0.079	0.098

Calibration and verification values are shown in terms of explained variance.

examined to evaluate the source of errors and corrections were made. For verification of these corrections, COFECHA was run again on the corrected measurements to check for further errors. Ring width series were detrended using 40 years cubic spline and were standardized to form tree ring indices using another computer program ARSTAN[10]. This method removes growth trends related to age and stand dynamics, while retaining the maximum common signal.

The present tree ring chronology extends from AD 1891 to AD 1996. The chronology suitable for climatic study is generally believed to have good correlation both between trees and within trees, high mean sensitivity, high standard deviation, high values of common variance and high signal-to-noise ratio. The chronology statistics for a common period, i.e. maximum available length of chronology in maximum number of samples, suggest that *LAGR* growing in the Eastern Himalayan region under mesic climatic conditions has moderate values of auto correlation, mean sensitivity, common variance and signal-to-noise ratio (Table 1). Autocorrelation is the association between ring width for the year $t-1$ and the widths of subsequently formed rings for the years t, $t+1$ to $t+k$, which can perturb the casual relationship between climate and tree growth[5]. In this chronology, autocorrelation was reduced to –0.061 after using autoregressive modelling, thereby demonstrating its feasibility in dendroclimatic studies.

To understand which climatic variables are significant in limiting growth of *LAGR* in the Eastern Himalayan region, the response function was computed. It involves a principal component and multiple regression analysis, with monthly climatic variables as predictors and the tree ring indices as the predictand. Due to non-availability of long climatic records close to the sampling site, an attempt was made to find out growth re-

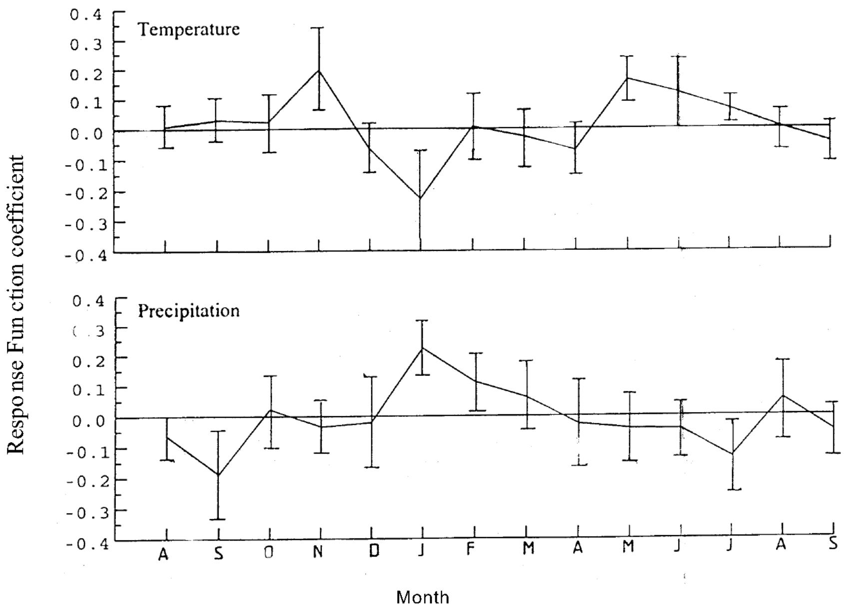

Figure 4. Response function analysis showing relationship between the growth of *LAGR* and climate.

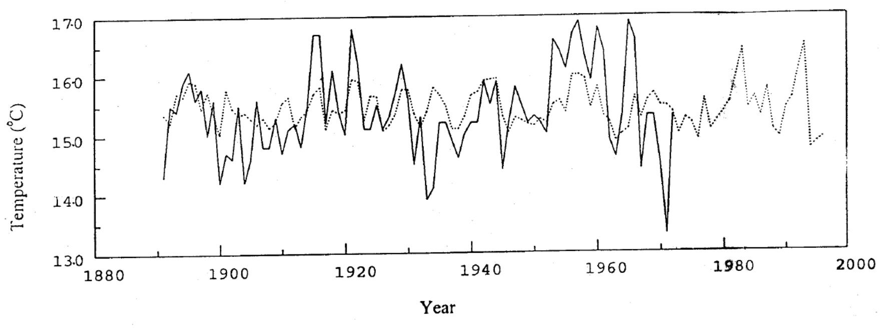

Figure 5. Observed (solid line) and reconstructed (dotted line) May temperatures. The reconstruction was calibrated using 1921–1978 temperature data at Darjeeling.

sponse in relation to available long climatic records of Darjeeling station (27°03'N and 88°16'E). The climatic records of Darjeeling cover a time span of AD 1848–1978. However in this record, data from 1854 to 1881 are completely missing, so data from 1882 onwards were used. Precipitation record extends from 1868 to 1987, with some missing values. All missing values in these climatic records were estimated by using a computer program, MET, of Dendrochronologyl Program Library[10] (developed by the Laboratory of Tree Ring Research, Tucson, Arizona, USA). In this program missing monthly data are estimated by setting the departure of the value from the mean for the month equal to the average departure of the other nearby stations. But since, such long records are not available from other stations of this region, mean of individual months of Darjeeling data itself was estimated and used to fill the missing values. In the analysis of tree growth climate relationship, climatic data from 1891 to 1978 (mean monthly temperature and monthly precipitation) and corresponding lengths of tree ring width data over an interval starting from August of the previous growth year to September of the current growth year were considered. The result of this analysis exhibits a higher growth in relation to increased temperature during November of the previous growth year and May and July of the current growth year, whereas current January temperature had negative relationship with tree growth. For precipitation, August and September of the previous year and July of the current year have an inverse relationship, whereas January and February of the current year exhibit a direct relationship with growth (Figure 4).

This study reveals that warmer conditions during May and July are favourable for growth. Low temperature during May leads to reduced ring width due to delay in start of the growing period. It is a general observation that for trees of sub-alpine cool humid conditions, increased summer temperature is favourable for growth. Physiological studies on sub-alpine conifers growing in the Alps have shown that at low temperature, water movement into the trees decreases sharply, resulting in stomatal closure and decreased carbon assimilation[11].

Generally, persistent low temperatures for long periods during winter at higher elevations are detrimental for both photosynthesis and respiration; but increase in temperature for a short period favours respiration over photosynthesis, as a result there is loss of stored food[11] and this might be the cause of negative relationship with the January temperature. But the positive relationship with increased winter temperature (November of the previous year) and tree growth recorded here might be due to the fact that the temperature during this period could not reach a low value to favour respiration over photosynthesis. Generally, the minimum temperature for net photosynthesis lies between –2 and –5°C, while respiration has been measured at –12°C. There are also evidences that some conifers in Northwest Pacific fix 30–65% of their annual carbohydrate during the dormant period[12,13]. There is a possibility that *LAGR* in the Eastern Himalayan region also could synthesize food, since day temperature during winter does not reach a sufficiently lower value as it happens in tree lines at higher latitude regions. Moreover, this tree sheds leaves during autumn[4], perhaps with the onset of cooler conditions. Thus increased temperature during November might have delayed shedding of leaves and chlorophyll remains active for a longer period for the photosynthesis. This enhances the net rate of photosynthesis resulting in the storage of more carbohydrate for growth in subsequent years. However, further studies on ecophysiological aspects are required from the Himalayan region to confirm this.

Higher winter precipitation may become favourable for tree growth by maintaining enough soil moisture for the rapid growth of trees during spring and early summer, before commencement of monsoon rains. However, in most cases, the amplitude of these relationships is not enough for reconstruction of such climatic variables.

For climatic reconstruction, calibration tests were conducted in which tree ring width chronology of *LAGR* was taken as predictor and individual months, as well as various combinations of monthly temperature, which were found significant in the response function, were predictands. We used cross calibration to calibrate and check the degree of association between predictor variable and climatic variation. The climatic data were spilt into sub-periods so that each sub-period could be compared with tree ring data for the years $t-1$, t and $t+1$. The calibrations were derived using an orthogonalized stepwise multiple regression analysis[15]. The first predictor variable was selected on the basis of F-value, significant at $P = 0.15$ to develop the final calibration equation (Table 2). The best reconstruction is for May using a single concurrent year predictor, model (t). This

Table 3. Calibration and verification statistics for the ring width chronology of *LAGR* as predictor of May temperature

	Calibration 1891–1920	Verification 1921–1978	Calibration 1921–1978	Verification 1891–1920
Multiple correlation coefficient	0.439*	0.168*	0.410*	0.193*
F-Value	6.691**		11.292***	
R^2	0.193	0.168	0.168	0.193
R^2 adjusted	0.164	0.153	0.153	0.164
t-value		2.773*		1.841*
Sign test		34/58		19/30
Reduction of error		0.147		0.166

Sign test = Number of agreements/total value.
$***P < 0.001$; $**P < 0.01$; $*P < 0.05$.

model explains 16.5% of the temperature variance in the first sub-period and 18.4% in the verification period.

In general, only the model 1 (i.e. t alone) showed significant results. Though variance explained by the other two models was high in some cases, significance level of these lagged variables in both models failed to equal the pre-set limit, i.e. t-value significant at $P < 0.05$.

For the reconstructed May temperature (Figure 5), calibration performed well for the verification period 1891–1920 that was not used in calibration (correlation coefficient 0.439; reduction of error 0.166; and product mean $t = 1.841$, Table 3).

The present study suggests that *LAGR* has good prospect in understanding fine resolution climatic changes from the Eastern Himalayan region using tree ring width data. It has all the characteristics which make it a potential parameter for the reconstruction of May temperature. Moreover distinct demarcation of early wood and late wood cells in the rings suggests that early wood and late wood measurements separately could be additional parameters, besides total ring width. Future analysis using these two tree ring parameters may help us understand climatic changes of other months also. Although the tree ring data discussed here are not enough (1896–1995 AD) to build long climatic records, these data could be extended further through cross dating with additional collections from older stands of this tree from the region. Thus the present tree ring study signifies its future perspective of long summer temperature reconstruction of this region.

1. Bhattacharyya, A. and Yadav, R. R., *IAWA*, 1999, **20.3**, 311–316.
2. Bhattacharyya, A., Yadav, R. R. and Chaudhary, V., *Himalayan Geol.*, 1997, **18**, 169–176.
3. Chaudhary, V., Bhattacharyya, A. and Yadav, R. R., *IAWA*, 1999, **203**, 317–324.
4. Sahni, K. C., *Gymnosperms of India and Adjacent Countries*, Bishen Singh, Mahendra Pal Singh, Dehradun, 1990.
5. Fritts, H. C., *Tree Rings and Climate*, Cambridge University Press, London, 1976, p. 567.
6. Schweingruber, F. H., *Tree Rings: Basics and Applications of Dendrochronology*, Kluwer Academic Publishers, Dordrecht, 1987, p. 276.
7. Cook, E. R. and Kairiukstis, L. A., *Methods of Dendrochronology: Applications in the Environmental Sciences*, Kluwer Academic Press, Dordrecht, 1990.
8. Stokes, M. A. and Smiley, T. L., *Introductions to Tree Ring Dating*, University of Chicago Press, USA, 1968, p. 73.
9. Holmes, R. L., *Tree Ring Bull.*, 1983, **43**, 69–78.
10. Holmes, R. L., *Dendrochronology Program Library User's Manual*, Laboratory of Tree Ring Research, University of Arizona, Tucson, USA, 1994.
11. Tranquillini, W., *Physiological Ecology of the Alpine Timberline*, Springer, Berlin, 1979, p. 137.
12. Emmingham, W. H. and Waring, R. H., *Can. J. For. Res.*, 1977, **7**, 165–174.
13. Waring, R. H. and Franklin, J. F., *Science*, 1979, **20**, 1248–1254.
14. Briffa, K. D., Jones, P. D., Pilcher, J.R. and Hughes, M. K., *Arct. Alp. Res.*, 1988, **20**, 385–394.
15. Fritts, H. C., Guiot, J., Gordon, G. A. and Schweingruber, F. H., in *Methods of Dendrochronology: Applications in the Environmental Sciences* (eds Cook, E. R. and Kairiukstis, L. A.), Kluwer Academic, Dordrecht, 1990, pp. 163–217.

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