Suitability of *Pinus kesiya* in Shillong, Meghalaya for tree-ring analyses

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Pinus kesiya (Royle ex Gordon) growing in and around Shillong plateau in the northeast of India, has been studied to understand its suitability for tree-ring analysis. Based on good replication of samples, five site chronologies were made from ring-width measurement of this tree, which range from 80 to 142 years. Synchronization of growth pattern recorded in the tree-ring sequences in most of the study sites suggests its suitability for tree-ring analyses. Correlation of tree-ring data of all these five site chronologies with the climate of Shillong indicates that there is no common climatic response to the growth of *P. kesiya* in this region. There is a significant positive relationship at two sites with precipitation during the month of December of the previous year and March in the growing year at two other sites.

PINUS *kesiya* (Khasi pine), a fast-growing, three-needle pine has immense value for its timber and good quality resin. Due to its over exploitation during the last several decades, it is presently restricted only in isolated patches of the Khasi and Naga hills in Shillong and in Manipur. It is also naturally distributed in Myanmar, Thailand and Philippines[1]. Dendroclimatic potentiality of this tree growing in Thailand has been discussed earlier[2,3], but no tree-ring data are available for this pine growing in the subtropical belt of the northeastern part of India. Earlier, tree-ring studies from this region were restricted to mostly temperate and sub-alpine forest[4,5] where trees are found to be sensitive to temperature variability. For detailed climatic studies of this region, tree-ring analysis needs to be extended to other geographical regions, possibly to explore the role of other climatic parameters on tree growth. Here, an attempt has been made to understand the suitability of Khasi pine growing in the subtropical belt around Shillong plateau for tree-ring analysis.

Khasi pine forest occurs at an elevation of 800–2000 m in Khasi hills, where it thrives at 1200–1400 m. It grows well in sheltered conditions, with a good depth of soil and good drainage[1]. Tree-ring samples from Khasi pines were collected from five different Reserved and Protected forests in and around Shillong between 91°47' and 91°55'E longitude and 35°31' and 35°39'N latitude (Figure 1). These forests are: Shyrwat Reserved Forest (SHY), Short Round Protected Forest (SRF), Riat Khwan Reserved Forest (RKF), Laitkor Protected Forest (LPF)

and Upper Shillong Reserved Forest (USF). In all these sites, except in cooler aspect at altitudes ranging from 950 to 1600 m, pines form a pure, open-canopy forest, and at the lower limit they are mixed with broad-leaved taxa. At the upper limit their growth becomes stunted, lichen-covered, and takes on a stag-headed appearance.

At SHY pines grow on rocky slopes with some small shrubs and grasses, between 1380 and 1500 m altitude. Ground fire is a common practice here and such fires have affected nearly all the trees on their lower side. In SRF, pines are distributed between 1420 and 1470 m altitude on undulating land with gentle slopes. For resin extraction, local people have gouged almost all the trees and some are burnt as well. Locals use resin and wooden chips as fuel. RKF lies on either side of the earlier (British period) Shillong–Guwahati road and is characterized by an open, mixed, broad-leaved pine forest between 950 and 1470 m. Pines here are confined to good soil cover in comparison to other forest sites and exhibit good height and volume. Most of these trees have cut-marks for resin extraction near the base of the trunk, and many also have fire scar-marks at the base. This forest is highly damaged as it is also the site for depositing the trash of the whole of Shillong. At LPF, which forms the catchment area for water supply of Shillong municipality, pine trees grow on steep slopes between 950 and 1560 m altitude along with *Rhododendron*, Oak, *Schima wallichi*, wild *Cinnamomum* and other trees. Chopping and burning has damaged the base of most of these trees (Figure 2). At USF cores were collected from pines growing along the roadside in Mawklot division and at another site, Moron, near Elephanta Falls. Cut marks are evident here also, but trees are not burnt afterwards as in the other sites.

The underlying rocks of all these forests are mainly sandstone of varying hardness, with some shales and quartzites in the RKF and LPF respectively. The rocks are overlain with a deposit of reddish clay of various
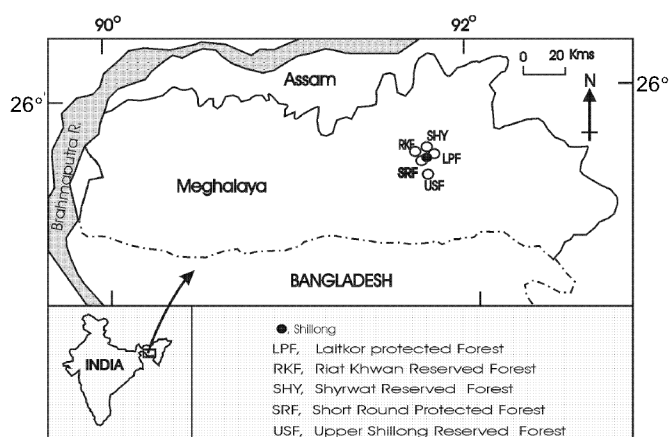
Figure 1. Location of tree-ring sampling sites (o) and meteorological station (●).

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Figure 2. View of *P. kesiya* forest in Shillong. The base of most of the trees is damaged because of chopping and burning.

depths. Despite being given the status of Reserved and Protected forest, almost all the existing pine trees have been exploited for resin extraction. The best growth of the pine trees as regard to height and volume is at an elevation of about 1200 m. Among these sites, RKF is considered as containing the best quality and USF the poorest quality pine[6].

For the present study, a total of 281 tree-ring cores from 143 pine trees were collected. Normally, two cores from each tree were collected through increment borer during December–January 2000. All the cores were mounted on wooden frames, cut and polished with several grades of sand paper to make the rings clear. Rings were later examined under the microscope. Inter-annual variability in ring width of *P. kesiya* is markedly clear. Each core was dated using 'cross-dating' technique[7] and then measured at 0.001 mm accuracy, using a sliding-stage micrometer interfaced with a computer. The dating was verified by a statistical method using a computer program COFECHA. This program tests each series against a master dating series (mean of all series) on the basis of correlation coefficients[8]. Later, all the cross-dated ring width series were detrended and standardized into a chronological form using the ARSTAN program[9]. Detrending for all the series was done using a 30-year spline which retained 50% of the variance contained in the measurement series at a wavelength of 30 years[10]. An auto-regressive model was also used to reduce the auto-correlation in the detrended series. The autocorrelation may be due to endogenous or exogenous disturbances. Standardized, individual ring-width series were averaged using the biweight robust procedure in the preparation of the mean chronology of each site. Two versions of the final chronology (standard and residual) were used for further analysis. In the standard (STD) version, after detrending, chronology is computed as a robust estimation of the mean value function, and in the residual (RES)

version, chronology has been pre-whitened by auto-regressive modelling.

Five site chronologies of *P. kesiya* were prepared, which range only from 82 to 142 years (Figure 3). The longest chronology is from LPF, which extends from 1859 to 2000. It is difficult to get living old trees here. The written records elsewhere show that before 1847, the forests in Shillong were jhumed (practice of shifting-cultivation) and grazing was unrestricted. The oldest of these forests was created in 1877. But after the earthquake of 1897, due to extensive demand for timber, mainly pine to rebuild the Shillong station, the USF and SRF were heavily logged during 1905 and 1906 (ref. 6).

The statistics for characteristics of mean chronologies of all the five sites is presented in Table 1. Mean sensitivity, a measure of the mean percentage change from each measured yearly ring value to the next, is found to be low (0.16 and 0.24) in all site chronologies. Autocorrelation is the association between ring width for the year $(t - 1)$ and the subsequently formed ring t, $t + 1$, to $t + k$. In all the chronologies this value is low, which indicates that growth during prior years does not have much influence on the growth during the subsequent years. Expressed population signal is a measure of the correlation between the mean chronology derived from the core samples and the population from which they are drawn[11]. A value of 0.85 has been put forward as a reasonable threshold, but none of these chronologies have crossed this value. Common variance between cores at a single site, as measured by signal-to-noise ratio (SNR) varies from 1.85 to 4.46. In general, SNR is low in these chronologies, but the SHY, LPF and SRF chronologies exhibit slightly better SNR in comparison to RKF and USF. The common variance is a mean of the correlation coefficients of all possible pairwise combinations of the ring-width index series over the common interval period. This value indicates the variance due to the common forcing factor having significant role in limiting the growth of trees over a wide area.

Among all these site chronologies, correlation for the common period (1921–2000) having good sample depth was calculated. Inter-chronology correlations are usually higher when common factors exert a greater influence, covering a wider area. It has been recorded that correlation exists among all the sites, except at RKF for both STD and RES chronologies (Table 2). The highest correlation exists between STD chronologies of SHY and SRF (0.657) and the lowest between RKF (RES) and SRF (STD) (0.152). In general, RKF has poor correlation with all the other chronologies, except LPF. Synchronization of growth pattern of Khasi pine in most of these sites covering a wide area of the Shillong plateau suggests common force controlling the growth of the region. Generally, common growth pattern is exhibited in trees where climate has a significant role in limiting the tree growth[12].
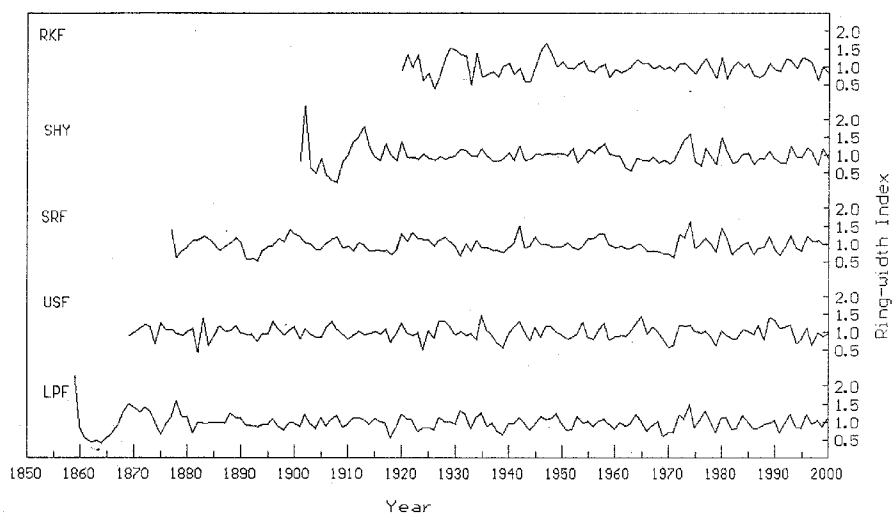
Figure 3. Ring width index chronology of *Pinus kesiya* in Shillong.

Table 1. Selected statistics of tree-ring chronology of *Pinus kesiya* at five sites in Shillong

	LPF	USF	SRF	SHY	RKF
Chronology time-span	1859–2000	1869–2000	1877–2000	1901–2000	1920–2000
No. of radii	90	37	54	38	34
Mean sensitivity	0.194	0.217	0.165	0.231	0.249
Standard deviation	0.233	0.197	0.197	0.287	0.243
Autocorrelation order-I	0.294	0.028	0.321	0.228	0.236
Common interval	1907–1996	1910–1984	1918–1997	1944–1999	1963–1995
No. of radii	37	25	44	31	33
Correlation among all radii	0.228	0.285	0.251	0.300	0.188
Correlation between trees	0.222	0.279	0.247	0.289	0.184
Correlation within trees	0.305	0.306	0.285	0.372	0.212
Signal-to-noise ratio	4.272	1.939	4.260	4.465	2.480
Expressed population signal	0.810	0.650	0.810	0.817	0.713
Variance in first eigenvector (%)	26.04	32.33	27.80	34.16	23.78

Table 2. Pearson correlation among *Pinus kesiya* at five different sites in Shillong (1921–2000)

	LPF-STD	LPF-RES	USF-STD	USF-RES	SRF-STD	SRF-RES	SHY-STD	SHY-RES	RKF-STD	RKF-RES
LPF-STD	1									
LPF-RES	0.963**	1								
USF-STD	0.540**	0.499**	1							
USF-RES	0.548**	0.517**	0.993**	1						
SRF-STD	0.541**	0.530**	0.366**	0.365**	1					
SRF-RES	0.532**	0.571**	0.366**	0.372**	0.945**	1				
SHY-STD	0.536**	0.503**	0.278*	0.286*	0.657**	0.631**	1			
SHY-RES	0.484**	0.479**	0.257*	0.264*	0.634**	0.650**	0.966	1		
RKF-STD	0.342**	0.329**	0.225*	0.225*	0.162	0.235*	0.227*	0.241*	1	
RKF-RES	0.289**	0.306**	0.202	0.206	0.152	0.240*	0.193	0.220*	0.955**	1

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level.

The growing season in this region is likely to be in the monsoon months of April to October, though the exact climatic requirement for the optimum growth of these trees is not known. For the study of tree growth–climate relationship, correlation functions between the site chronologies and climatic variables were analysed. Climatic

records obtained from the meteorological observatory at Shillong were used in the present study. The station provides the longest record of climate in this region. The mean temperature and total precipitation records are available from 1903 and 1867 respectively. Besides this, the maximum and minimum temperatures are also avail-

able from 1962 to 1999. For the year 1961, no tempera-ture and precipitation data were available. Hence these missing values are calculated by taking the mean of all the years.

In Shillong the mean maximum and minimum temperature in summer are 23.5 and 16.7°C respectively, whereas in winter these are 15.9 and 6.6°C respectively. Here, January is the coldest (9.9°C), June the wettest (455.6 mm) and July the hottest (20.96°C) months of the year (Figure 4). The lowest humidity is around 55% and occurs during March–April. It increases to a maximum of about 86% in August. Annual average rainfall is 2163 mm.

Correlation analysis was done individually for all the sites using the residual chronologies of the respective sites with the available maximum, minimum and mean temperature and total monthly rainfall. A 17-month den-droclimatic year was used for correlation extending from the previous August to the December of the growing sea-son for the period 1904–1999. The results show that cor-relation between temperature and precipitation for most of the months is weak and statistically not significant. Besides, the role of significant months/seasons on growth was not common to each site, despite the fact that all these sites are within 20–25 km area. This anomaly in growth pattern may be due to the different site character-istics and also due to human disturbances which mask the climatic influences.

The LPF chronology showed significant negative cor-relation with the maximum temperature in June, whereas no month was found significant when correlated with minimum temperature. It also shows significant positive correlation with precipitation of previous December and current April, and negative correlation with mean tem-perature of previous December and current May (Figure 5). The direct relationship with the previous December rainfall is also significant at SRF. It has been recorded

that December is the driest month in Shillong, having an average rainfall of 8.42 mm; thus the lower precipitation causes the water-stress condition. This positive relation-ship with previous December precipitation is exhibited throughout the chronology, but there are some years in which this relationship does not exist, e.g. in the year 1982 despite the heaviest rainfall (87.2 mm) during that month, there was below-average growth at all the sites except RKF, whereas in 1974 when the precipitation was comparatively of the same amount (84.0 mm), above-average growth had been recorded in all the sites except RKF. At LPF, there was near about average growth dur-ing 1882–87, showing no effect of comparatively high rainfall in 1884 (41.9 mm).

At USF, precipitation during March of the growing season and the previous September–October shows posi-tive relationship, whereas temperature during March and precipitation during November show negative relation-ship. March is another dry period of the year in this region. Pre-monsoon precipitation seems to be beneficial for the initiation of cambial activity and rapid develop-ment of early wood cells. This positive relationship with precipitation during March is also significant at RKF. Besides, precipitation during April also shows signifi-cantly positive relationship, while temperature during October shows negative relationship with RKF chronol-ogy. At SHY, in general, no significant relationship was found among chronology and any of the climatic vari-ables (Figure 5).

A 30-year time interval (starting from 1905) with a 5-year sliding period was taken individually for each site, to find out which portion has low correlation with the climatic data. Analysis shows low correlation and a sharp decrease in variance explained by the climate during 1921–51 and 1959–71 at SHY, 1909–26, 1930–40 and 1975–86 at USF, 1930–41, 1943–54 and 1950–71 at SRF, and 1916–36 at LPF (Figure 6). During these inter-vals meteorological data do not show any major changes, so it can be inferred that non-climatic factors rather than climate factors were more significant. These disturbances seem to be site-specific, since these periods are not com-mon to all the sites.

We do not have enough historical account to verify the different growth patterns related to non-climatic influ-ences on tree growth. As mentioned earlier, the effect of heavy logging during 1905–06 could be noted in the form of wider rings at USF and SRF. This increase in growth may be due to release effect resulting from the lack of competition among trees. Though we do not have any other records of large-scale logging, there was a sharp increase in growth at SHY in 1908 and in 1972 at all sites except RKF. Similar is the case in the year 1940 at LPF, USF and SRF. During 1959–71 there was below-average growth in SHY and SRF. Besides, there were two more periods (1921–30 and 1943–51) in which below-average growth was recorded at SHY. Moreover, trees growing in
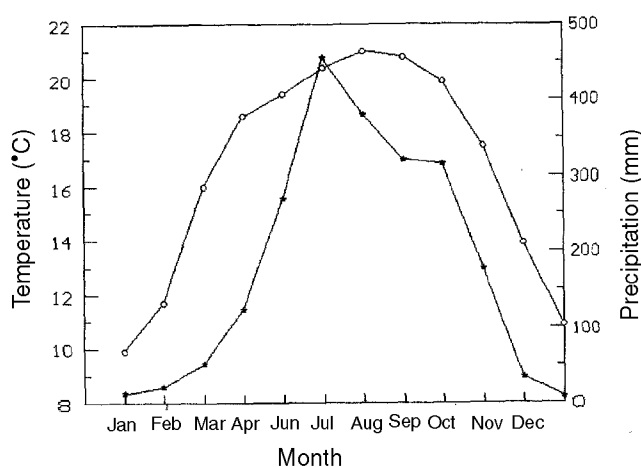
Figure 4. Average monthly precipitation (–*–) and mean temperature (–O–) at Shillong based on data from 1903 to 1999.
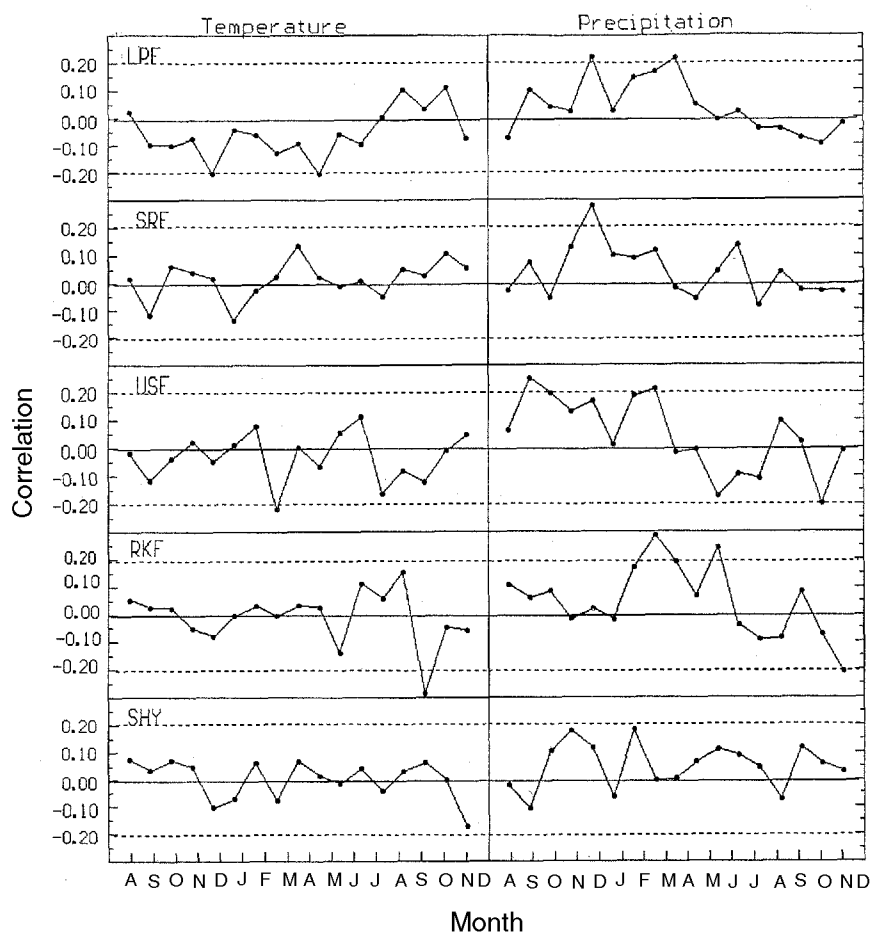
Figure 5. Correlation of individual site chronologies with mean temperature and average precipitation from August of the previous year to December of the growing period in Shillong. Dotted lines indicate the 95% confidence limit.

Shillong plateau have been facing varied intensities of earthquakes from time to time, since this is one of the most tectonically sensitive zones of the Eastern Himalayan region. Generally, trees which survive the devastating effects of strong earthquakes exhibit several features in their rings like growth suppression, growth eccentricity, formation of reaction wood, etc. During the last 150 years, the strongest earthquake of magnitude 8.7 occurred in 1897 in this region. The signature of this earthquake has been recorded in the tree-rings of 1898 in the form of comparatively reduced growth only in some trees, as most of the trees in the present study have been dated younger than 1897. Generally, it is difficult to recognize such features delineating earthquakes in young trees or saplings. In future, attempts will be made to collect samples from old trees growing along fault lines for detailed palaeoseismic analysis from this region.

The present study clearly indicates that *P. kesiya* growing in and around Shillong, northeastern India, is suitable for tree-ring analysis for its clear and datable tree-ring

sequences and synchrony in growth pattern. A significantly positive correlation recorded at two sites with the precipitation during the previous December, and with the precipitation during March of the growing year at the other two sites indicates the potential of tree-ring data in climatic reconstruction. However, changes in the response of significant climatic variables in same species at different locations and low SNR might have resulted due to the different site characteristics, especially the nature of soil, slope, immense human disturbances (logging, lopping, faulty agricultural practice, fire, etc.), and also effects of frequent earthquakes of different magnitudes which reduce the climatic signal in tree-ring data. However, the same species growing at Nam Nao National Park, Thailand showed a direct relationship with total monthly precipitation for November of the growing season[2].

The prospects of tree-ring data of Khasi pine in dating palaeoseismic events have also been brought out in the present study. Tree-rings have been recorded to be nar-
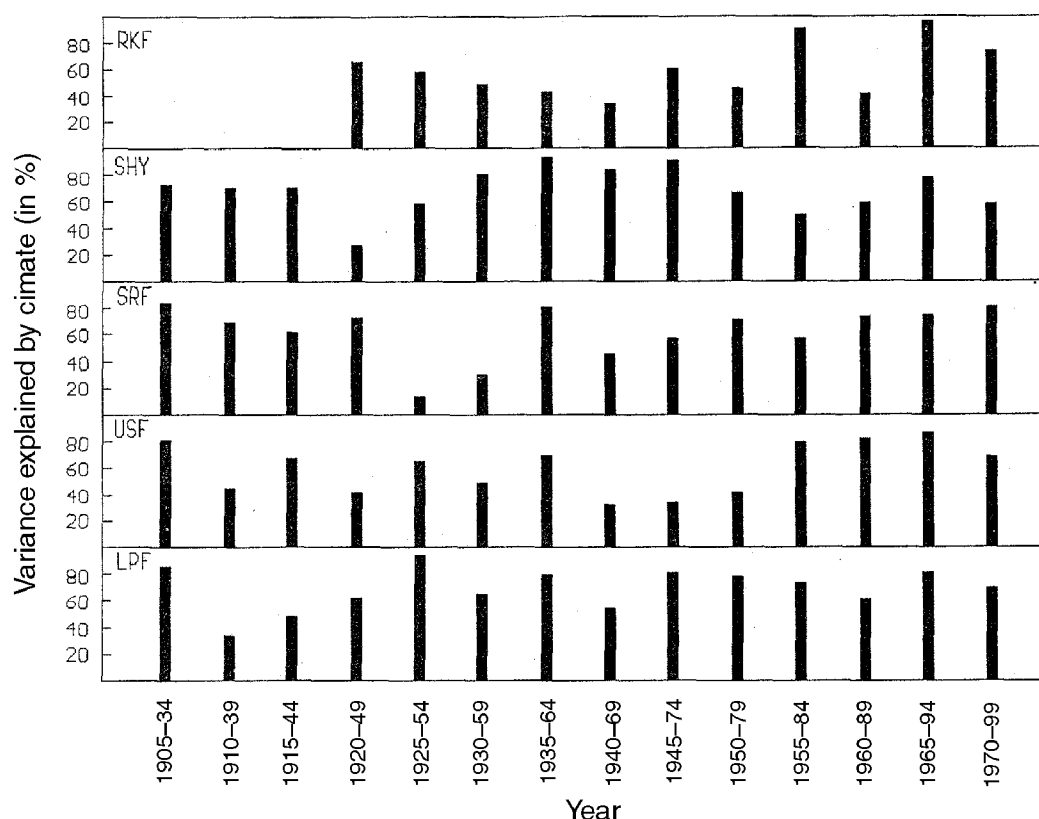
Figure 6. Plot showing change in variance explained by climate through time. A 30-year interval with 5-year sliding period was taken for the analysis.

rower in this region during years subsequent to the major earthquake in 1897. The data generated in the present study are not sufficient to either reconstruct the climate back to the existing 133 years of meteorological records of this region or to date older palaeoseismic events. For this we need long tree-ring data. As mentioned earlier, it is difficult to get older living trees from this region because of over exploitation of Khasi pine, mainly for the construction of houses. However, collection of tree-ring samples from ancient timbers used for construction purposes may provide long tree-ring sequences. In this context, present tree-ring data could be useful to date such long tree-ring records through cross-dating. Synchronization of growth pattern recorded in the study site suggests this possibility.

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