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Climatological signals from the annual growth-rings of selected tree species of India

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सार — भारतीय क्षेत्र के वृक्षों की कुछ चुनी हुई जातियों की वृद्धि-संरचना का स्थानीय पर्यावरण के सापेक्ष अध्ययन किया गया है पश्चिमी घाटों से सागौन और नैनीताल क्षेत्र से चीड़ के पेड़ों के नमूने लेकर उनके वृद्धिवलय का विश्लेषण किया गया है। नमूनों के वलय विस्तार के आंकड़ों से पर्यावरण के बारे में महत्वपूर्ण संकेत मिले हैं। अनुक्रिया फलन विश्लेषण और बहुरैखिक समाश्रयण की विधियों का उपयोग करके वृक्ष-वृद्धि और पर्यावरण के संबंध का अध्ययन किया गया है। उत्तर प्रदेश की पहाड़ियों में भीषण अनावृष्टि के ऐतिहासिक और जलवायु संबंधी आंकड़ों की उस क्षेत्र में चीड़ के वृक्षों के वलय-विस्तार सूचकांक के संदर्भ में जांच की गई है।

ABSTRACT. Growth pattern of selected tree species of the Indian region is studied in relation to its local environment. Growth-ring analysis is done for the samples of Teak from Western Ghats and Chir Pine from Nainital region. Ring-width data for the samples show a significant environmental signal. The tree-growth/environment relationship is studied using the response function analysis and multiple linear regression technique. The historical and climatological data on severe droughts in western U.P. hills is examined in relation to the ring-width index values for Chir from the region.

1. Introduction

The basic constituents of the biosphere, the carbon, hydrogen and oxygen are derived from the local environment by a complex process. Certain tree species with well defined growth periods faithfully record the integrated environmental information in the form of their annual growth-rings. As a tree grows older the width of each growth-ring generally diminishes as a function of age. Superimposed on this detectable pattern there are often significant variations in the width of individual rings or group of rings that reflect the climatological conditions favourable or detrimental to growth.

2. Methodology

The samples comprise of full discs cut from the stems of old and healthy trees about a meter above the root level. One of the smooth cut sides of the disc is polished with an extra fine sand paper till the cell structure is clearly detectable under microscope. A few rings surrounding the pith of the tree for Chir and Teak are shown in Figs. 1 (a) and 1 (b) respectively. Original rings are magnified 6.6 times before photography. Method of assigning exact years of formation to each ring is known as dating of the samples. Dating procedure consists of the cross matching of ring pattern among the samples starting from the last year of growth (Stokes and Smiley 1968). The ring-width is measured to an accuracy of 10^{-3} cm using a microscope coupled increment measuring device.

The ring width data are standardized into ring-width indices using a cubic spline technique (Cook and Peters 1981). The parameters of the fitted spline are adjusted to take into account the varying growth rates during the young, active and old periods of the tree growth. The spline is set to filter the low frequency signal to remove 50% of the variance to be explained by the signals of periods $\geqslant 25$ years. The measured ring-width is divided by the standard curve value to produce a dimensionless ring-width index for each ring. This is known as standardization. Principal component analysis is done using the monthly rainfall and temperature values for the year of growth and the year prior to growth. The most significant components (at 5% level) are pooled together to perform a multivariate analysis specially adapted for tree-ring study.

Details of the method are described in (Fritts 1976, Fritts *et al.* 1971). Brief description using standard matrix notations is given below :

The normalized climatological data are subjected to routine principal component analysis.

$$ {}_mC_m\, E_m = {}_mE_m\, L_m \quad m = \text{total number of climatic variables} \quad (1) $$

Where, ${}_mC_m$ is the correlation matrix of the climatic variables. ${}_mL_m$ the diagonal matrix of eigen values and ${}_mE_m$ the complete eigen vector matrix corresponding to the eigen values L_i, $i = 1 \ldots .m$. ${}_mC_m$ is given by the relation :

$$ {}_mC_m = (1/n)\, {}_mF_n\, F'_m \quad (2) $$

${}_mF_n =$ the data matrix, where,

$n =$ the number of observations for each variable.

${}_nF'_m =$ the transpose of the data matrix.

The most important orthogonal eigen-vectors (p) are selected from the eigen-vector matrix (the variables which account for the 95% of the total variance) and represents the ways that temperature and precipitation may covary.

The amplitudes, or multipliers, of these orthogonal eigen vectors denoted by ${}_pX_n$, are then obtained.

$$ {}_pX_n = {}_pE'_m\, F_n, \qquad p < m \quad (3) $$

Stepwise multiple regression is used to estimate a ring-width series for a climatological region, ${}_1\hat{P}_n$ from the amplitudes representing the climatic variables for that region,

$$ {}_1\hat{P}_n = {}_1R_p\, X_n \quad (4) $$

where, ${}_1R_p$ is a row vector of significant regression coefficients (all insignificant ones are assigned a zero value). Combining Eqns. (3) and (4) we get,

$$ {}_1\hat{P}_n = {}_1R_p\, E'_m\, F_n = {}_1T_m\, F_n \quad (5) $$

Thus, climatic data ${}_mF_n$ are transformed into estimates of ring-width indices ${}_1\hat{p}_n$ via a transfer or response function denoted by ${}_1T_m$.

To derive the normalised value of certain climatic anomaly use is made of the multiple regression functions of the canonically weighted amplitudes of the tree growth field eigen vectors. The equations are identical to the one used in Eqn. (5). The transfer function transforms a matrix of normalized tree-ring data into estimates of climatic anomally at the individual grid points or the station.

The average mean sensitivity (${}_mS_x$) of a tree-ring series (Douglass 1936) is a parameter frequently used to assess the climatic potential of the tree-ring series. It is a measure of the relative difference in width from one ring to the next. It is calculated using the relation

$$ {}_mS_x = \frac{1}{n-1} \sum_{t=1}^{t=n-1} \left| \frac{2(X_{t+1} - X_t)}{X_{t+1} + X_t} \right| $$

where X_t is each datum, the vertical lines designate the absolute value of the term enclosed by them and n is the number of data points. The value of mean sensitivity ranges from 0 where there is no difference to 2 where a zero value occurs next to a non-zero one in time sequence.

3. Samples and sites

The species selected have a wide geographical distribution and are one among the major species of the relatively undisturbed forest regions of the country (Pant 1979). The Teak (Tectona grandis, Linn. f) samples were selected from the tropical forest of Western Ghats within a range of 60 km (mean location 100 km NE of Bombay). The Chir (Pinus roxburghii, Sarg.) samples were selected from the forest area around Nainital with the tree sites almost equally separated from each other in the hill ranges between 20-50 km and the altitudes of the sites varying between 1850 m to 1525 m asl. The last year of growth in all the samples in 1980 except for one of Chir which is 1979. Four samples each of above two species were selected for analysis.

4. Results and discussion

Three samples of Teak could be cross matched and dated. Taking measurements along two radii for each sample provided six ring-width data series for Teak. Only two samples of Chir could cross match. With two radii for each sample considered only four data series are obtained for Chir. The plots shown in Fig. 2 (Skeleton plots) indicate the strength of the common environmental signal. Height of the plots are proportional to the relative narrowness of the rings. Coherency of the signal is indicated by the grouping of the vertical lines while examining the plots one above the other with the last year of growth in one line for all the plots.

4.1. *Teak*

Seven plots in the upper part of Fig. 2 are for Teak. First six plots are for the three Teak samples with two radii per sample. The bottom most plot for Teak is a composite made for all the six plots. Cross match among two radii of a sample is excellent though there is assymetric growth around the ring centre. All positive correlations shown in Table 1 with some of them

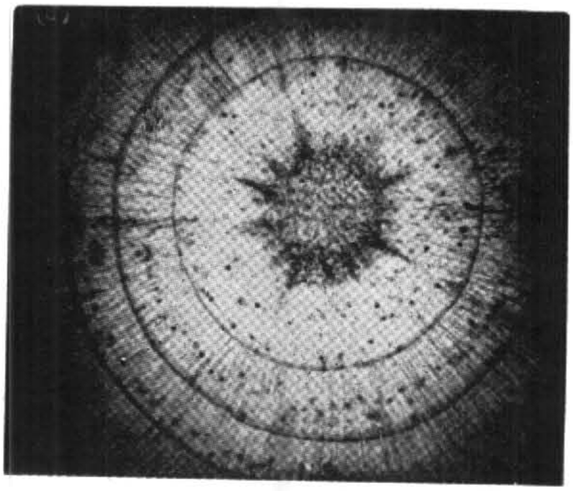

Fig. 1(a). Growth-rings in Chir (magnification=6.6)

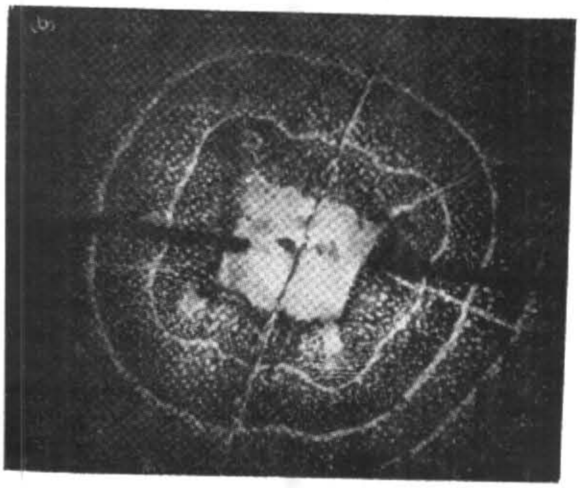

Fig. 1(b). Growth-rings in Teak (magnification=6.6)

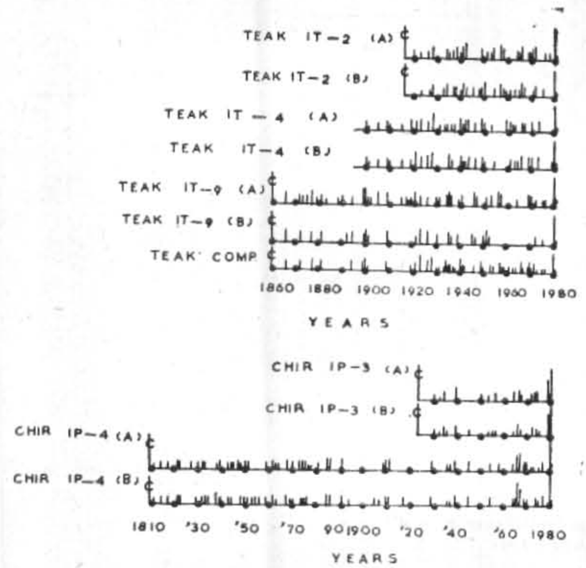

Fig. 2. Skelton plots for Teak and Chir sections considered for analysis

TABLE 1

Cross correlation for the period common to all the series (1918-1980)*

S. No.	1	2	3	4	5	6
1	1.00	*0.41*	*0.33*	*0.45*	0.17	0.14
2	*0.44*	1.00	0.05	0.05	0.08	0.23
3	0.22	0.20	1.00	*0.67*	0.01	0.04
4	*0.43*	0.22	*0.54*	1.00	0.20	0.01
5	0.22	0.04	0.21	*0.30*	1.00	0.05
6	0.13	*0.26*	*0.33*	0.22	0.24	1.00

*(Values above the diagonal are the linear correlations among the series and the values below the diagonal are the linear correlations after constructing new series where the data points are the difference between the values of two consecutive years. Values significant at 5% level are given in italics. Critical value using a two tail test is=0.25).

within the statistical significance limits suggest the detectable environmental signal. It is particularly important since the sample size is small with no choice for deleting less representative samples. The average mean sensitivity of the samples is 0.30.

The difference series shows higher correlation values indicating that the year to year variations show a better association.

The first 4 series are for the two trees from one site few kilometers from each other whereas the last two series are for the third tree which is about 40 km away from the first site and is much older. Inclusion of this sample increases the length of the final series substantially but the signal strength decreases. It is indicated by the fact that the average value of cross correlation between the four series of first two samples is 0.33 and the principal component analysis shows that the four series have 51% variance in common (Peter *et al.* 1981). Including the third sample in analysis gives the value of average cross correlation as 0.21 and the common variance explained drops to 36%. This analysis will be specially helpful in detecting the spatial extent of the forest site within which a reasonable positive correlation is obtained by the analysis of additional samples.

The response function analysis indicates that the temperature of the neighbouring meteorological station (Bombay) shows an extremely weak response thus does not appear to limit the growth. Using 24 variables of the current year and the year prior to growth the rainfall values (Thane) occurring in order of their significance (at 5% level) are the October of the year prior to growth, October and May months of the growth year. The heavy rains during the months June, July and August on many occasions are seen to respond negatively to growth, probably, because of the decreased transpiration and sunshine during heavy cloud cover. The results make biological and hydrological sense in that the increased soil moisture at the beginning of the dry season and the carryover effects in the physiological processes of the tree (Fritts 1976) can both contribute to tree growth.

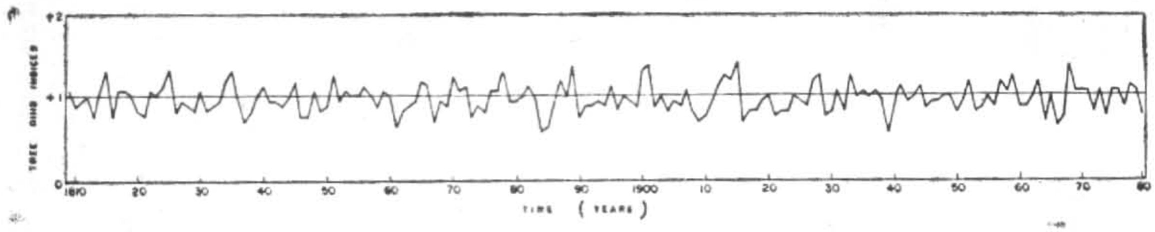

Fig. 3. Tree-ring index series for Chir

TABLE 2

Cross correlation for the period common to all the series (1924-1979)*

S. No.	1	2	3	4
1	1.00	0.70	0.18	0.31
2	0.82	1.00	0.23	0.37
3	0.26	0.25	1.00	0.60
4	0.33	0.36	0.65	1.00

*(Details as in Table 1, critical value using a two tail test=0.275).

4.2. *Chir*

Four plots in lower part of Fig. 2 are for two samples of Chir with two radii of each indicated by (A) and (B). There is an excellent match among the two samples. The cross correlation values are given in Table 2.

The tree-ring index series (1809-1980) for Chir plotted as an average for all the four series is depicted in Fig. 3. The average cross correlation for all the four series is 0.40 and the principal component analysis shows that the four series have 50% variance in common, indicating a significant common signal from the site. The average mean sensitivity for the samples is 0.19. The series shows a serial correlation of 0.081.

The climatic data used for the environmental response analysis are the mean monthly temperature for Mukteswar and precipitation for Nainital. The procedure followed is similar to the one discussed for Teak. Response curve indicating a combined effect of precipitation and temperature on tree growth is depicted in Fig. 4. It can be seen that the most significant direct responses for growth in Chir is from hot-dry summer and cold-wet winter prior to growth and a warm-wet growing season.

The response function coefficients for Chir as shown in Fig. 4 are used to estimate the rainfall and temperature series for 1903-1975 and the relationship is independently verified using the data set for the period 1871-1902. Reconstruction of rainfall and temperature series does not provide the values acceptable within the prescribed error bounds at 5% confidence level. The present set of tree-ring data does not provide enough spatial distribution to reconstruct the climatic anomaly field for the region.

Considering only precipitation as a limiting factor on Chir growth, it found that the years of extreme droughts in a wider region (to minimize the effect of local events in a highly mountanous area) are well reflected by the smaller index values (less than 1.00), indicating that actual average annual growth during the year of drought and the year after that has less than the values obtained by the best fit curve. The average value of mean tree-ring index for the severe drought years and the year after drought in the region, are given in Table 3.

The years 1837, 1867 and 1892 are specifically described as severe drought years in the region. The years 1873, 1892, 1939 and 1965 are designated as severe drought years on the basis of rainfall analysis. Areal mean annual precipitation for six stations in the region (Almora, Nainital, Pithoragarh, Paurigarhwal, Chamoli and Dehradun), for the period 1871-1978 has a mean value 159 cm and standard deviation of 28 cm. The years with rainfall value less than two standard deviation from the areal mean are designated as the severe drought years.

It is seen from the table that severe drought years are marked by small index values indicating narrow growth-rings in relation to the normal growth pattern.

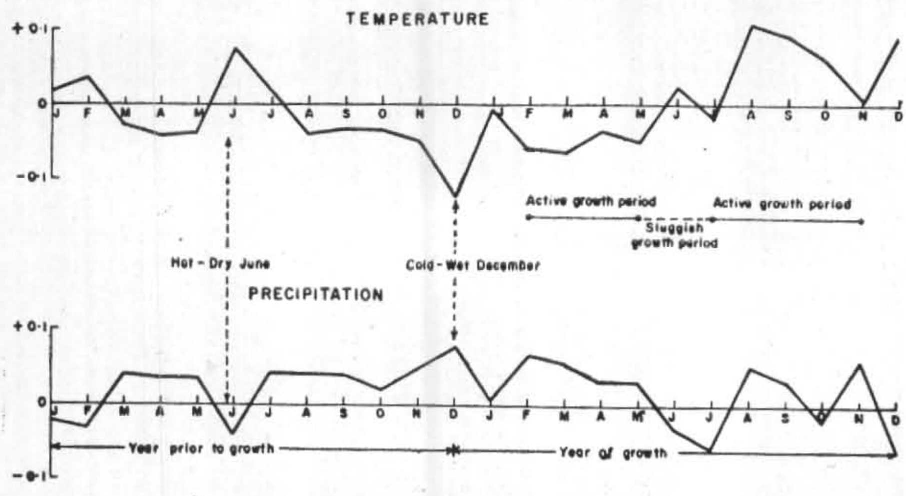

Fig. 4. Coefficients used in the response function model based on ring width index for Chir and 48 variables of mean monthly climatological data (1903-1975)

TABLE 3

Years of severe drought in Kumaon and Garhwal region (Uttar Pradesh) and tree-ring index values for Chir

Years	Tree-ring index (mean, 1809-1980 =1.00 and standard deviation =0.17)	References/criteria on droughts
1837	0.78	Girdlestone, C.E.R. 1868 : Report on the past famines in north-west provinces page-61.
1867	0.82	Girdlestone, C.E.R. 1868 : Report on the past famines in north-west provinces page-96.
1873	0.82	*
1892	0.91	Report of the Indian Famine Commission 1898 page-19.*
1939	0.77	*
1965	0.83	*

*Areal mean annual rainfall value is less than twice the standard deviation from the mean.

5. Conclusions

Preliminary investigations on tree growth-climate relationship suggest that the annual growth-rings of the species examined contain a significant climatological signal. Analysis of Teak from Western Ghat indicates that the rainfall during the period prior to growing season shows a significant correlation with radial growth. Length of the monsoon season has a direct correlation with tree growth, though the total amount of rainfall during the year shows a significant relation only during the years of extreme climatic stress. Temperature in the region being equitable throughout the year does not show any direct response to growth.

The Chir samples show a combined response of rainfall and temperature. The severe drought years in the region are all characterized by associated low index values. The reconstruction of meteorological fields does not provide satisfactory results, probably because of small sample size.

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