Dendroclimatic analysis of teak (*Tectona grandis* L. f.) annual rings from two locations of peninsular India

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Climate-related tree-growth variability in teak (*Tectona grandis* L. f.) has been studied based on response function analysis from dry deciduous forests of Mundagod (Karnataka) and Chandrapur (Maharashtra), peninsular India, representing two ecological zones. Rainfall during the monsoon months of the current year was found to be positively associated with radial growth of teak at both sites, whereas pre-monsoon April rainfall was found to be negatively associated. Rainfall and temperature of the current year during March have positive influence on the growth of teak at Chandrapur and Mundagod respectively. Furthermore, rainfall during October of the preceding year showed negative influence on tree growth at Mundagod and positive influence at Chandrapur, which might be due to the difference in relative humidity and soil type at both the locations, apart from soil moisture.

Keywords: Annual rings, climate variability, tree growth, teak.

THE pattern of radial growth in trees depends largely on the climatic conditions of different localities[1–3]. Dominated by monsoon climate, the tropical dry deciduous forests of Karnataka and Maharashtra could form important sites for dendroclimatic analysis, especially in understanding tree-growth responses to climate. Attempts are being made to retrieve climatic information using annual growth rings of trees from several locations in India. Growth rings in a large number of tropical trees are studied as annual[4]. It is estimated that about 25% of the total number of tree species produces growth rings[1,2]. Among these, teak exhibits datability of growth rings in trees to the exact formative year, which is a pre-requisite for dendrochronology. India is considered to be the only known centre for genetic diversity and variability of teak[5], having its natural distribution zone confined predominantly to the peninsular region below 24°N lat. It is reported that the location factor contributed as much as 31.4%, whereas seed origin contributed only 1.46% for variability in teak growth[6]. Teak has been a subject of dendrochronological studies representing different forest types. It has been studied at several locations, viz. from moist deciduous forest in Thane, Maharashtra[7–9]; dry deciduous forest in Korzi, Andhra Pradesh[10], the Western Ghats of Kerala[11,12], upper Narmada river basin in Central India[13] and dry deciduous forest of Madhya Pradesh[14,15]. These exploratory studies revealed that annual rings in teak could be valuable proxy data for dendroclimatic analysis. As dry deciduous forests of Karnataka and Maharashtra are well known for the best teak-growing locations in peninsular India, Mundagod and Chandrapur regions were selected for the present study. No detailed tree-ring analysis has been reported so far from these two locations as to how teak growth is influenced by changes in rainfall and temperature. An attempt has been made to study climate-related tree-growth variability in teak with reference to rainfall and temperature from these two locations.

Ten cross-sectional discs of teak were collected in April 1999 from the base of felled trees at Yellapur Forest Division, Mundagod (14°58′N lat. and 75°1′60″E long.), Karnataka and 15 discs were collected in November 2006 at the base of logged trees from Mamla forest range of Lohara around Chandrapur (19°57′N lat. and 79°E long.), Maharashtra (Figure 1). Totally 25 discs, one from each individual trunk, were collected for tree-ring analysis either from the base of the logged trees or from the leftover stumps. The mean monthly temperature and rainfall data of two meteorological stations, viz. Belgaum and Chandrapur close to the tree-ring sampling sites have been used in the response function analysis of Mundagod and Chandrapur tree-ring samples. This record extends from AD 1941 to 1999 and AD 1901 to 2000 for Mundagod and Chandrapur regions respectively (Figure 2).

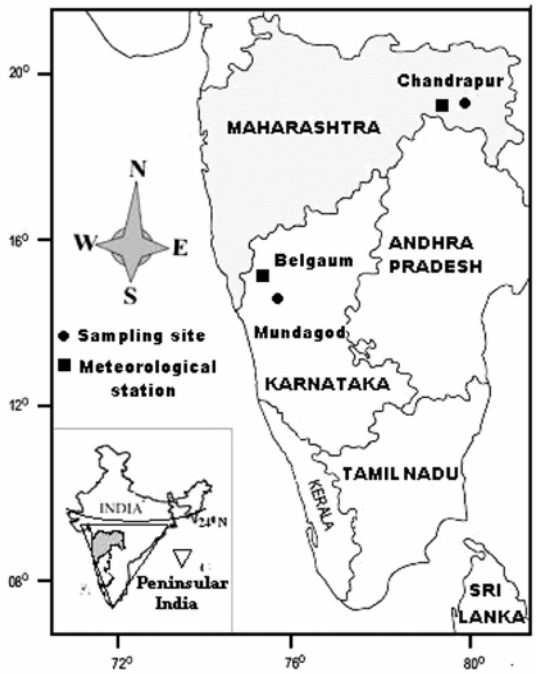

Figure 1. Location of tree-ring sampling sites and meteorological stations used in the present study.

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The surfaces of 25 discs were smoothened using different grades of sand paper to expose the growth rings and prepare the wood for microscopic analysis. A long radial strip of 1.5 cm width was cut from each disc collected from Mundagod and Chandrapur, including all rings from pith to bark. Each ring of the radial strip was dated to the calendar year of its formation applying cross-dating technique[16]. Ring widths along two radii of each disc from Mundagod and along a single radius from Chandrapur were measured to the nearest 0.01 mm under a Leica stereo-zoom microscope with a linear stage (Velmex) interfaced with a computer system to record the measurements. These measurements and dates were re-checked using the computer program COFECHA[17,18] for any error in the measurement or dating of the samples.

Data were standardized to form site–tree-ring–width-index chronologies using detrending methods, viz. negative exponential or cubic spline fit of wavelength equal to 38.58% of N, where N is the number of data points in individual tree-ring series in the computer program ARSTAN[18–21], and chronologies of 59 and 132 years were prepared spanning AD 1941–1999 and AD 1875–2006 along with sample size variation from Mundagod and Chandrapur regions respectively (Figure 3 *a* and *b*). The statistical properties of ring-width-index chronologies from the two sites (Table 1) assessed for their dendroclimatic potential. The chronology suitable for dendroclimatic study is generally believed to have good correlation between trees, high mean sensitivity, high standard deviation, high value of common variance, high signal-to-noise ratio (SNR), and high expressed population signal (EPS). Wigley *et al.*[22] suggest that chronologies with EPS ≥ 0.85 can be accepted as reliable chronology for dendroclimatic analysis. Moderately high values of standard deviation, mean sensitivity, EPS and common variance (mean correlation among all the tree samples) indicate the high dendroclimatic potential of these two chronologies. The value of SNR is moderately high for both chronologies, with the highest SNR for Chandrapur chronology. The values of different statistics of the chronologies after autoregression (residual version) are depicted in Table 1. The values in parenthesis are without autoregressive modelling. It was observed that after autoregression the overall statistical performance of tree-ring chronologies had improved. However, with these two chronologies climatic reconstruction is not possible as data are for a short period only.

Table 1. General statistics of tree-ring chronologies (values within brackets are without autoregressive modelling)

	Mundagod	Chandrapur
Chronology timespan	AD 1941–1999	AD 1875–2006
Number of trees (radii)	10 (19)	15 (15)
Mean tree-ring width (mm)	2.14	2.97
Mean sensitivity	0.220	0.306
Standard deviation	0.319	0.281
Lag-1 autocorrelation	0.02 (0.61)	–0.05 (0.13)
Common interval timespan	1944–1999	1956–1994
Number of trees (radii)	9 (18)	15 (15)
Mean correlation between trees	0.247	0.312
Signal-to-noise ratio	5.902	6.813
Expressed population signal	0.855	0.872
Variance explained percentage in first eigenvector	30.95	38.18

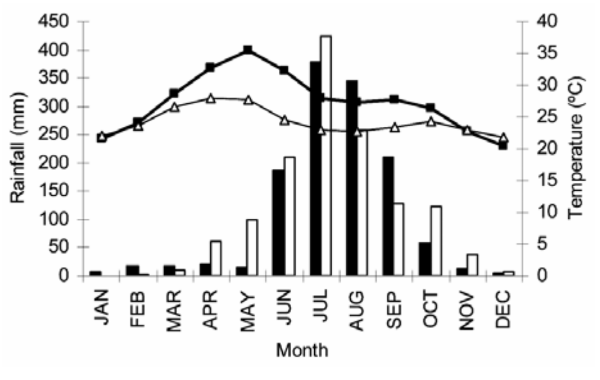

Figure 2. Average monthly variation of rainfall (white bars) and mean temperature (triangles with thin line) at Belgaum (Karnataka) based on the data period from AD 1941 to 1999, and average monthly variation of rainfall (black bars) and mean temperature (squares with thick line) at Chandrapur (Maharashtra) based on the data period from AD 1901 to 2000.

Climate–tree-growth associations can be assessed reliably by means of response function analysis[23]. This procedure is a multiple regression analysis in which monthly climatic parameters (temperature and rainfall) are predictors and tree-ring parameters are predictants. The resulting regression equation quantifies the response of the tree to variations in the most important climatic variables. Monthly mean temperature and rainfall at Mundagod and Chandrapur were entered as predictor variables and tree-ring indices as the predictant variables. The analyses were based on the time period 1941–1999 for Mundagod and 1901–2000 for Chandrapur, which were common to both meteorological and tree-ring data respectively. The initiation of growth period in teak starts around March and reaches a peak in June–July, and by the first week of October there is no wood formation. Shedding of leaves starts by December and by the first week of February, all the trees are leafless[1–3,24]. In constructing the response functions, a total of 26 variables were used as predictor variables, including 13 for temperature and 13 for rainfall from the previous October (end of previous growing season) to the current October (end of current growing season). Since many of the climatic variables are highly intercorrelated, principal components for 26 data series were obtained. Ring-width-index chronologies of Mundagod and Chandrapur were regressed on the climate principal components to obtain response-function coefficients. Standardized regression coefficients for response functions on a monthly scale for tree-ring chronologies from Mundagod and Chandrapur

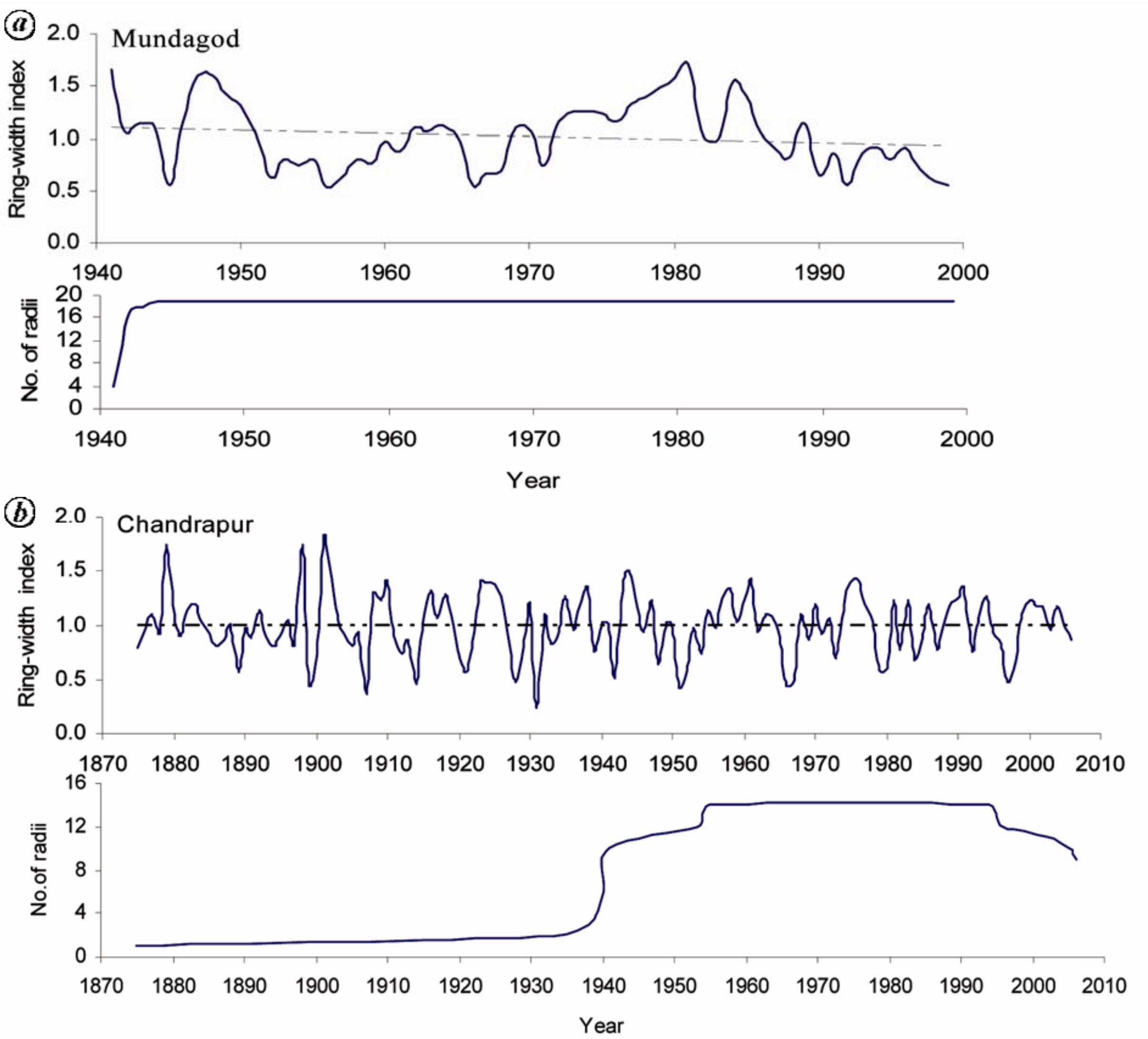

Figure 3. Tree-ring chronology of *Tectona grandis* from (***a***) Mundagod along with the number of radii extending from AD 1941 to 1999 and (***b***) Chandrapur along with the number of radii extending from AD 1875 to 2006.

are depicted in Figure 4. Vertical bars in the figure indicate 95% confidence interval; the coefficient is considered to be statistically significant ($P \leq 0.05$) only when its confidence interval does not include zero.

Analysis of tree-growth and climate relationship at Mundagod suggests that rainfall during June–August of the current year had positive influence on the growth of teak, whereas April rainfall of the current year and October rainfall of the preceding year had negative influence. March temperature during current year showed positive response with tree growth, whereas April temperature showed negative. Positive tree growth and climate relationship during June–August of the current year suggests that the southwest monsoon rainfall plays an important role in the growth of teak. Mundagod is situated in the eastern part of the Western Ghats, which is a hot, semi-arid ecological region having negligible coastal effects. It is evident from the average annual rainfall of 1116.9 mm and high potential evaportranspiration (PET) of 1600–1800 mm, that relative humidity in this region is low[25], predominantly with laterite soil, where October rainfall of the preceding year showed negative influence on tree growth. This might be due to nonavailability of moisture and nutrients as meagre rainfall may have eluviated the nutrients to the nonavailability zone. Experience in India has indicated that teak performs poorly on laterite soils[26,27]. The inverse relationship with April rainfall and April temperature might be due to lower net photosynthetic rate, presumably due to higher evapotranspiration. During these months rainfall is less, but temperature is at its maximum in the region (Figure 2). Thus increased rainfall during the hot summer accelerates the rate of evapotranspiration, which might have caused water stress-like conditions for teak trees[14]. March temperature

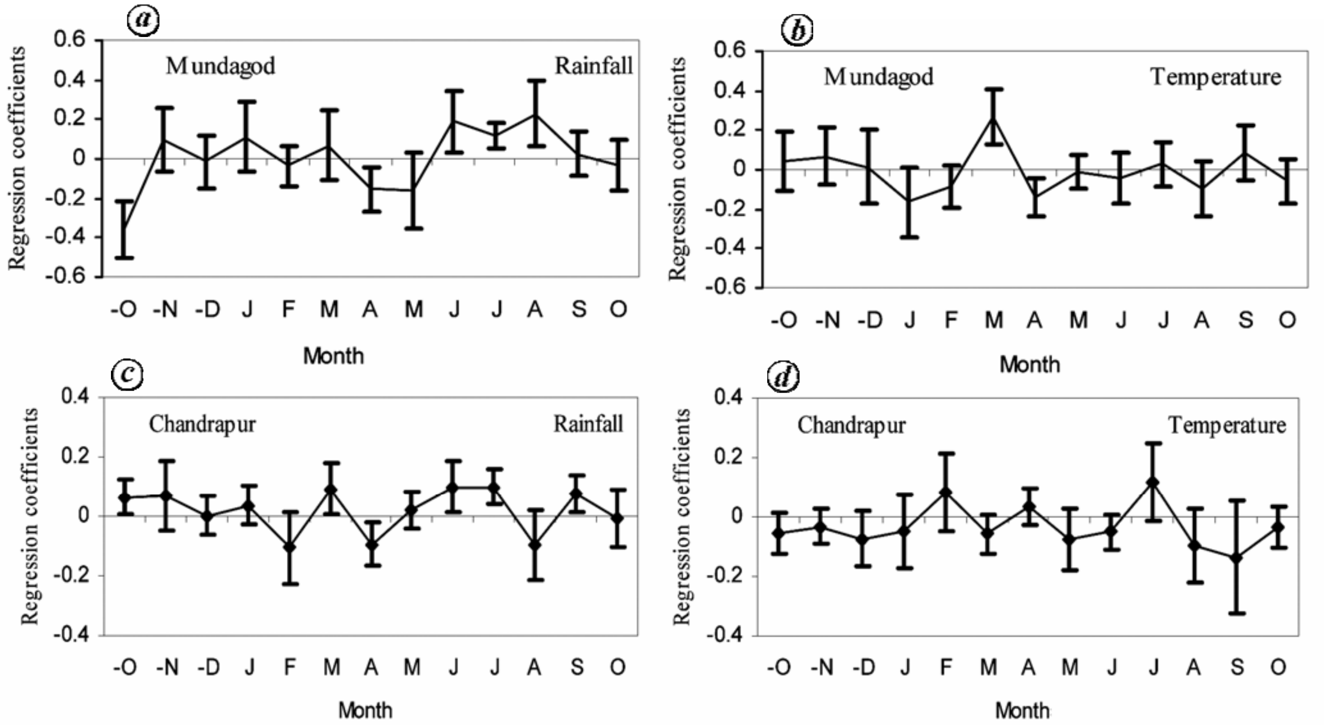

Figure 4 *a–d*. Response functions of tree-ring chronologies of teak at Mundagod and Chandrapur using monthly temperature and rainfall at Belgaum and Chandrapur respectively. Vertical bars indicate 95% confidence interval.

showed significant effect on the growth of teak, as it favours opening of dormant foliar buds and also the initiation of cambial activity[1,2,28].

Analysis of tree growth and climate relationship at Chandrapur suggests that the rainfall during March and June–September of the current year and October of the preceding year has positive influence, whereas April rainfall has negative influence on the growth of teak. Temperature does not show any significant effect on the growth of teak in this region (Figure 4 *c* and *d*). Positive tree growth and climate relationship during June–September suggests that the southwest monsoon rainfall plays an important role in the growth of teak. Besides, rainfall during October of the previous year also plays an important role. This might be due to mobilization of stored nutrients that aid in the initiation of growth for coming growing season[14]. This may also be due to high relative humidity because Chandrapur falls under the hot, semi-humid ecological region. The average annual rainfall in this region is 1275.3 mm, PET is 1400–1700 mm (ref. 25), and soil type of the region is sandy loam. In this type of soil, drainage and aeration is more, which is essential for better root growth. Aeration helps soil organisms to survive. These organisms often help by making nutrients available to the plants. Rainfall during March also showed positive response to tree growth. This is supported by a study, where pre-monsoon showers were recorded to play an important role in breaking cambial dormancy of teak[24]. The inverse relationship with April temperature might be due to lower net photosynthetic rate, concomitant with higher rate of evapotranspiration. During April–May, rainfall is less and temperature is maximum in this region (Figure 2). Thus increased rainfall during the hot summer accelerates the rate of evapotranspiration, which might have caused water stress-like conditions for teak growth.

Tree-ring analysis of teak from peninsular India has great importance since it adds novel information to understanding the chronological variability in the growth of teak with changes in climate. Mundagod and Chandrapur are dominated by the southwest monsoon with similar dry deciduous forests. However, a radial variation in the growth of teak has been studied at both the locations. This study corroborates that the pattern of radial growth in teak varies with the local edaphic and climatic conditions, mainly rainfall, relative humidity and temperature as well as soil type of different locations and plays a significant role in influencing the growth of teak.

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Psychophily in *Stachytarpheta jamaicensis* (L.) Vahl. (Verbenaceae)

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Stachytarpheta jamaicensis **is a seasonal shrub which produces flowers for a lengthy period during rainy and winter seasons. The floral characteristics such as bluish-violet flowers, no perceptible smell, narrow tubular corolla and concealed nectar accumulated at the corolla base conform to 'psychophilous pollination syndrome'. The aggregated arrangement of flowers on the inflorescence is economical and energetically rewarding for the butterflies. The lower lip of the corolla is elaborate and provides comfortable landing place for the butterflies. The nectar is sucrose-rich with 28% sugar concentration and also carbohydrate-rich with little protein content. It is also an important source of five of the ten essential amino acids required by butterflies; they include isoleucine, valine, lysine, methionine and threonine. Further, it also contains the non-essential amino acids such as alanine, butyric acid, cystine, glutamic acid, glysine, hydroxyproline, proline, serine, aspartic acid and cysteine. With these floral morphological and functional characteristics, the plant is exclusively pollinated by butterflies. Among butterflies, nymphalids and pierids are relatively more diverse in species and consistent foragers than papilionids and hesperiids. Therefore, the interaction between** ***S. jamaicensis*** **and the butterflies is mutualistic; the former for pollination and the latter for nourishment. This floral source is available for a long period and hence is an important nectar source for the maintenance of local butterflies. Additionally, bees also visit the flowers for forage and their visits**

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