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Responses of Short period ring width and mean vessel area Chronologies of Plantation grown teak (*Tectona grandis* L. f.) to Climate in Thrissur, Kerala, India

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Abstract

Investigations on relationship between short period chronological characters (ring width, mean vessel area) and climate (rainfall, temperature) offour teak (Tectona grandis L. f.) plantations in Thrissur district, Kerala were carried out. Ring width index chronologies were positively correlated with the previous year monsoons (south west and north east) and annual rainfall whilemean vessel area index (MVA) chronologies showed significant positive correlation with the previous year south west monsoon, north east monsoon, annual rainfall, previous year October-November temperature, October-November temperature and annual temperature. It can be concluded that short period tree ring chronologies of teak have good potential for dendroclimatic reconstruction for Kerala.

Keywords: Teak, ring width, MVA, chronology, Kerala.

Introduction

Annual growth rings in trees indicate the age and growth rate of the trees[1]. The variability of annual radial increments is predominantly determined by the climate of the vegetation period. Annual rings in trees to a large degree reflect the changes of the regional climate, the tree ring patterns in the same stand and climatic region are similar[1]. Compared to those hardwoods which grow in high latitudes, most of the tropical hardwood trees have been least preferred for tree ring studies because of the absence of distinct seasons like spring, summer, fall and winter in the tropical regions. This in turn leads to the absence of a clear cambial inactivity failing to produce distinct growth rings as a result of which majority of the tropical hardwoods are diffuse porous. Investigations on growth rings by Gamble was the pioneering dendrochronological work in tropical trees[2].About twenty five per cent of tropical tree species produce growth rings, majority of them being softwood species growing within the tropical regions[3,4]. Many trees in the tropical forests of the Indian subcontinent are known to produce growth rings[2]. Growth rings which indicate the year of formation are shown by only very few species such as *Tectona grandis* L. f. (Teak) among the tropical hardwood trees, which are otherwise generally poor in datability[5]. Teak is a high quality timber species which is widely distributed in the central and peninsular parts of India. Teak, being a ring porous species, shows distinct annual growth ring patterns useful for dendroclimatological studies. India is the centre of genetic diversity of teak and variability is very high[6]. Natural distribution zone of teak is concentrated in the peninsular region of India, mainly up to 24°N latitude. The variability in wood characters of teak is mainly contributed by locality factors than provenance or seed origin[7]. Climatic conditions prevailing in different localities are the main driving factors that influence the radial growth in trees[8].

Dominated by monsoon climate, Kerala could form important site for understanding tree growth responses to climate. Also the usefulness of teak for dendroclimatic investigations as well as reconstructions like rainfall, temperature, moisture index, ENSO (El-Nino Southern Oscillation) index and Palmer Drought Severity Index (PDSI) has been already reported[9-15]. The parameters like vessel area, vessel diameter and vessel frequency in a tree ring have been recognized as important factors in recent dendro climatic studies. However, an extensive network of tree ring/ mean vessel area (MVA) chronologies from Kerala will be of much use as they can be used as to detect past variations of rainfall/temperature and how it influences the growth of teak. Also, only a few studies have used short period chronologies to understand how tree ring features and climate are related. The present investigation was carried out to develop basic tree ring chronologies of teak grown as plantations in Thrissur district, Kerala to find their response to climate and also finding out whether any climate-mean vessel area (MVA) relationship of significance exists in teak.

Material and Methods

The samples used in the study were collected from Thrissur forest division and Chalakudy forest division of Thrissur district, Kerala figure-1. The Thrissur division has a total forest area of 29, 805 ha out of which 1816 ha comprise of 47 teak plantations of varying ages and sizes[16]. The Chalakudy forest division has a total forest area of 27, 870 ha out of which 4535 ha are under 90 different teak plantations[16]. The study areas selected in the Thrissur forest division were located in Elanad, Vazhani and Ponganamkadu, while Karikadam was the study site located in Chalakudy forest division. Details of the locations selected for the study from Thrissur forest division and Chalakudy forest division are given in table-1.

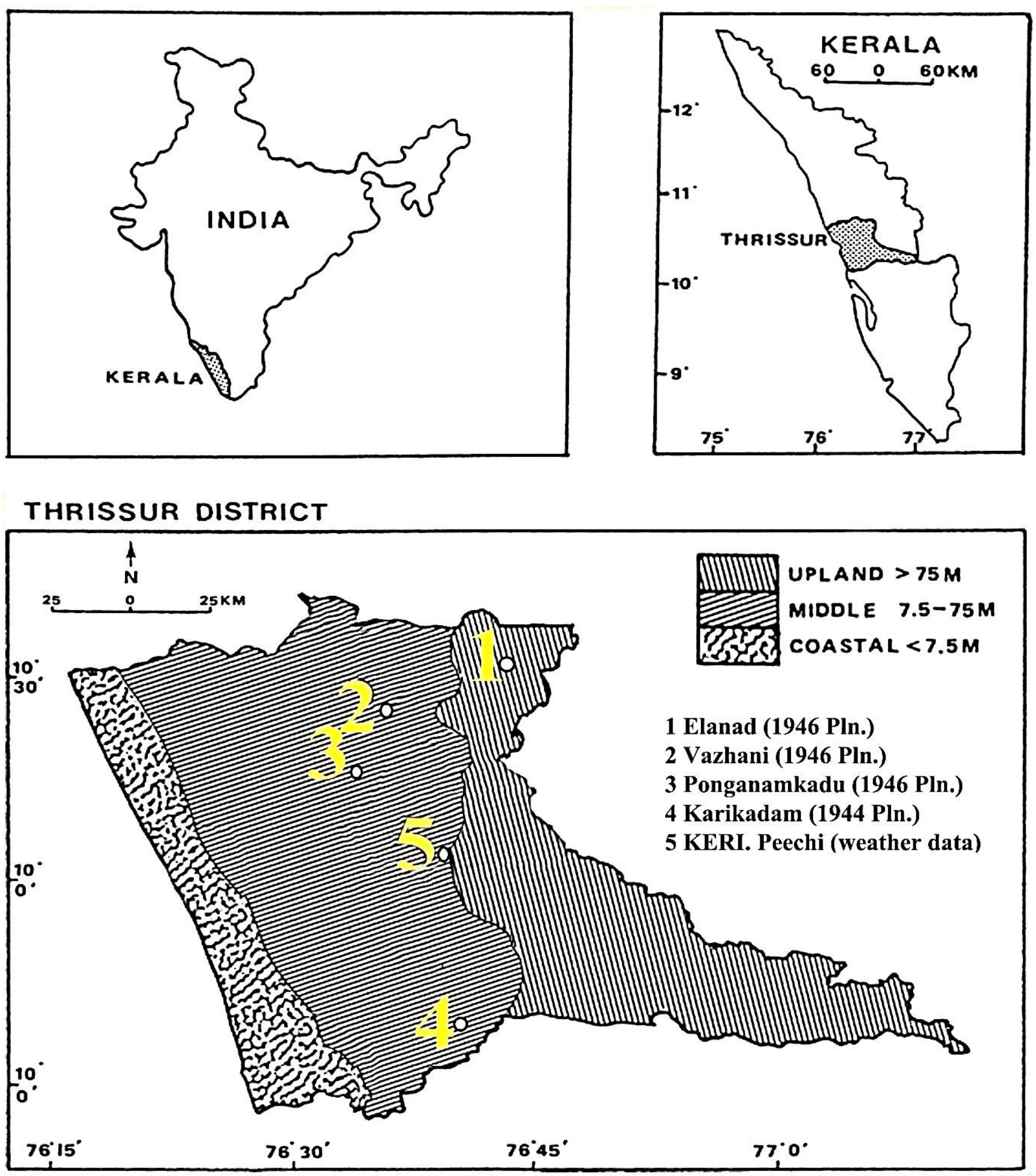


Figure-1
Map showing the study area and weather station

Table-1
Details of study sites

Sl. No.	Site	Area (ha)	Year of planting	Age
1	Elanad	31.92	1946	62
2	Vazhani	50.00	1946	62
3	Ponganamkadu	32.00	1946	62
4	Karikadam	33.39	1944	65

The samples were collected from stumps left over after final felling of plantations. Ten cross-sectional discs, one from each tree, were collected from each plantation. Totally, 40 discs were collected from all the four study sites. A portable chain saw was used to cut the basal discs from the left over stumps. The upper surface of the basal discs collected from the field was first planed with a portable hand planer. Then the disc surfaces were smoothened with sand paper of grit sizes 30, 60, 80 and 120 successively to clearly reveal the tree-rings for measuring ring width. To measure mean vessel area, selected radii were first planed and sanded with sand paper of grit sizes 30, 60, 80, 120, 220, 320 and 400 successively. The samples were then washed with a water jet to make vessel lumen clearly visible.

The growth rings were counted and cross matched within and between four radii on each disc from specific sites after sanding. Images of the selected rings were captured across the radius using a high resolution digital camera and ring width measurements were done in computer by image analysis using the software Digimizer (Version 3.8.1). The average ring width of each year obtained from the different radii was used to construct the chronology. Four radii were selected from each site to measure the mean vessel area. Macro images of the selected rings were captured across the radius using a digital camera and were used for vessel area measurements. Standardization process involved the removal of non-climatic signal of biological and/or tree disturbances (exogenous) where the tree-ring data by employing an appropriate curve fit to the tree-ring data series and calculating a new time series. In this investigation a smoothing spline[17]was used for standardization using the statistical package PAST (Paleontological Statistics Version 2.07). The selected radii were cross dated using the procedures suggested by Stokes and Smiley[18]. Ring width and mean vessel area (MVA) chronologies were developed using the index values obtained.

The relationship between climate and tree growth was examined for the available climate data period 1980-2005. Correlation analysis of tree ring data (ring width index and mean vessel area index) versus seasonal rainfall and temperature using the statistical package PAST (Paleontological Statistics Version 2.07) was performed. Seasons were defined as previous south west monsoon (–JJAS), previous north east monsoon (-ON), south west monsoon (June–September; JJAS), post monsoon or northeast monsoon October–November; ON), winter (December–February; DJF), summer (March–May; MAM) and annual[13].

Results and Discussion

Raw ring width and mean vessel area at all four sites showed an age related growth trend. After standardization, the ring width and MVA chronologies were developed for all the sites figure-2 and figure-3. Chronology statistics such as average ring width, mean vessel area, expressed population signal (EPS), and signal-to-noise ratio (SNR) are shown in table-2. All ring width index chronologies had the acceptable range of EPS values with Karikadam (1.419) having the highest. In the case of mean vessel area index chronology also the EPS values were showing future potential with Karika dam showing the highest (1.412). The expressed population signal (EPS) is a statistical measure to determine how best the limited sample index agree with the theoretical infinite population index of trees[19]. The value of EPS ranges from 0 to 1.0, generally chronologies with expressed population signal (EPS) ≥ 0.85 are recognized as dependable for dendroclimatological applications[20].

The values of SNR of ring width index chronologies from the four study sites are moderately high. SNRs were in the order Vazhani (6.79) > Ponganamkadu (6.72)> Karikadam (5.29) > Elanad (5.61). The chronology appropriate for dendroclimatological investigation normally should have attributes like good correlation between trees, high standard deviation, high SNR, and high EPS. Moderately high values of mean correlation, standard deviation, SNR and EPS of samples used in this study point toa high potential of these short ring width and mean vessel area index chronologies from Thrissur and Chalakudy forest divisions in Kerala, for use in dendroclimatology.

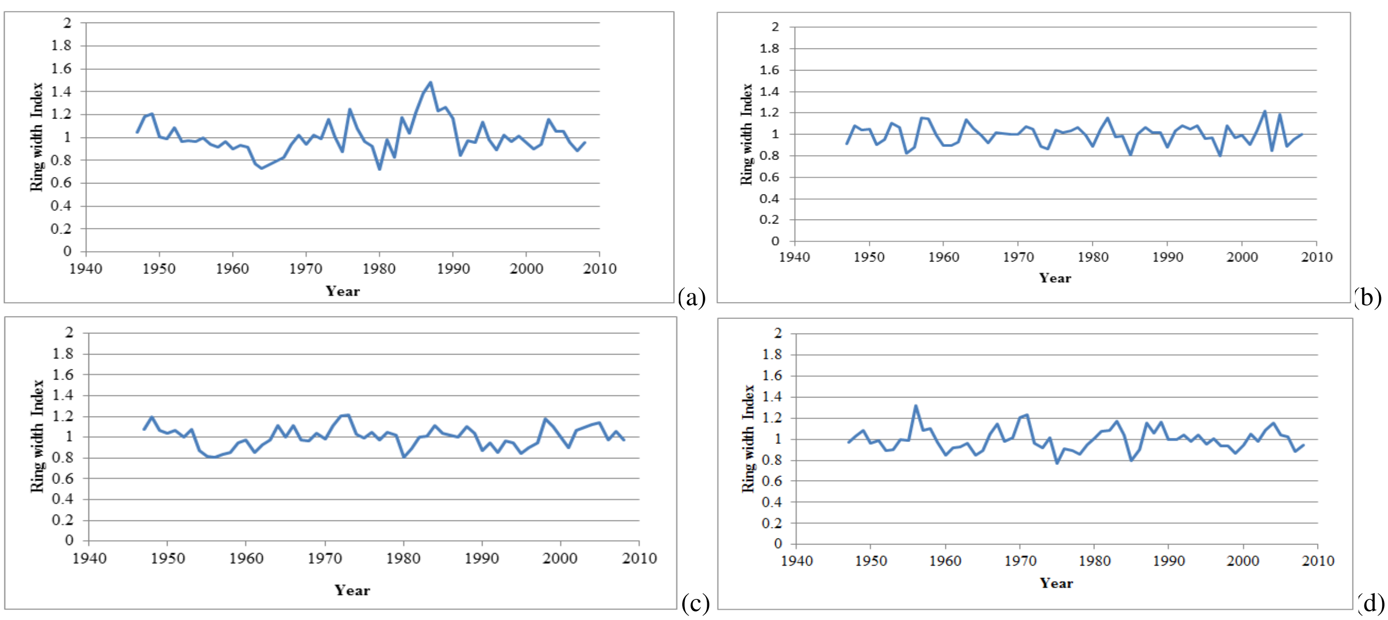


Figure-2

Average ring width index chronology of *Tectona grandis* at (a) Elanad; (b) Vazhani;(c) Ponganamkadu and (d) Karikadam

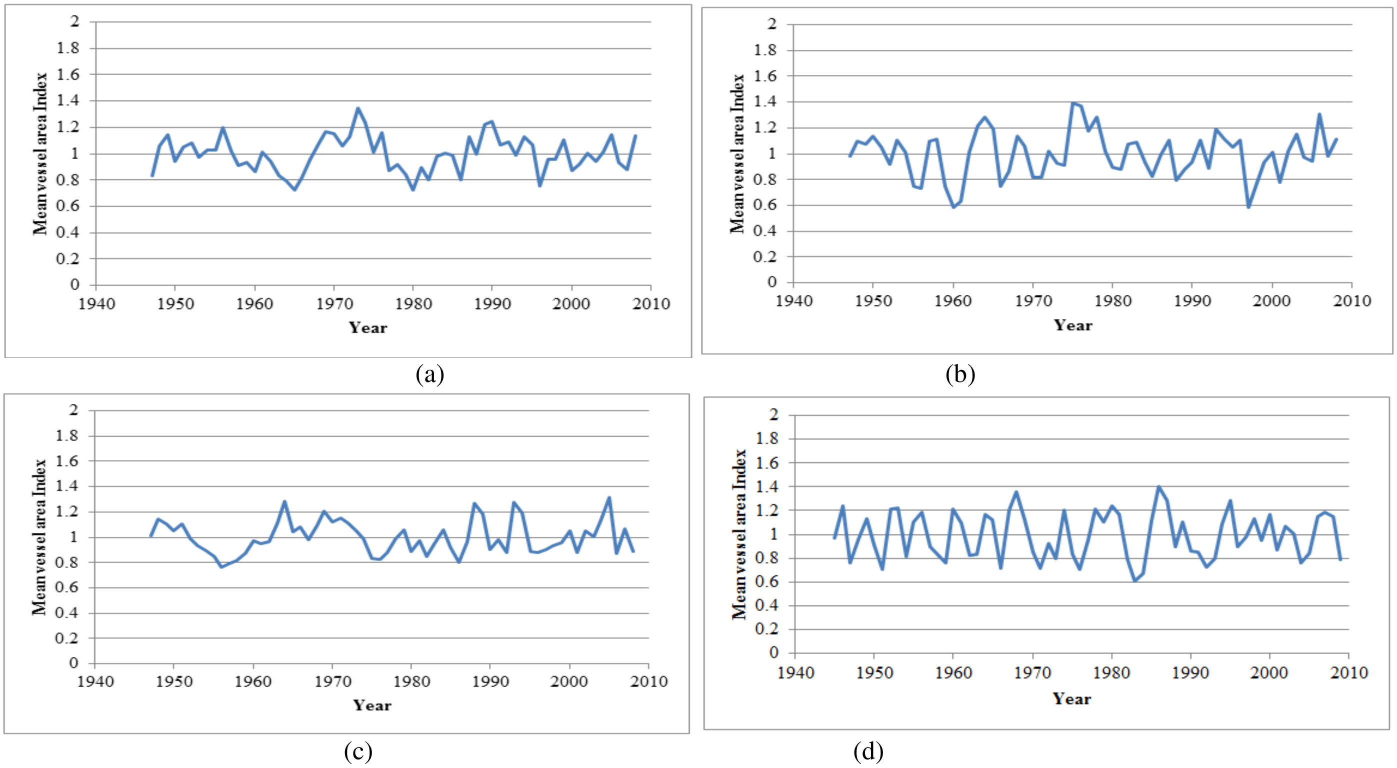


Figure-3
Mean vessel area index chronology of *Tectona grandis* at (a) Elanad; (b) Vazhani; (c) Ponganamkadu and (d) Karikadam

Table-2
Tree ring chronology statistics of *Tectona grandis* from the study sites

Tree ring chronology statistics	**Study sites**			
	Elanad	**Vazhani**	**Ponganamkadu**	**Karikadam**
Chronology time span	1946-2008	1946-2008	1946-2008	1945-2009
Number of trees	10	10	10	10
Number of radii	40	40	40	40
Average ring width (mm)	4.66	5.56	4.98	3.36
Mean vessel area (μm^2)	41020	47250	37319	23096
Mean correlation among all radii	0.422^{+} 0.645*	0.219^{+} 0.631*	0.363^{+} 0.533*	0.452^{+} 0.525*
Mean correlation between trees	0.767^{+} 0.638*	0.693^{+} 0.755*	0.699^{+} 0.747*	0.581^{+} 0.588*
Signal to noise ratio	6.90^{+} 5.61*	6.24^{+} 6.79*	6.29^{+} 6.72*	5.23^{+} 5.29*
Expressed population signal	1.233^{+} 1.362*	1.307^{+} 1.245*	1.301^{+} 1.253*	1.419^{+} 1.412*

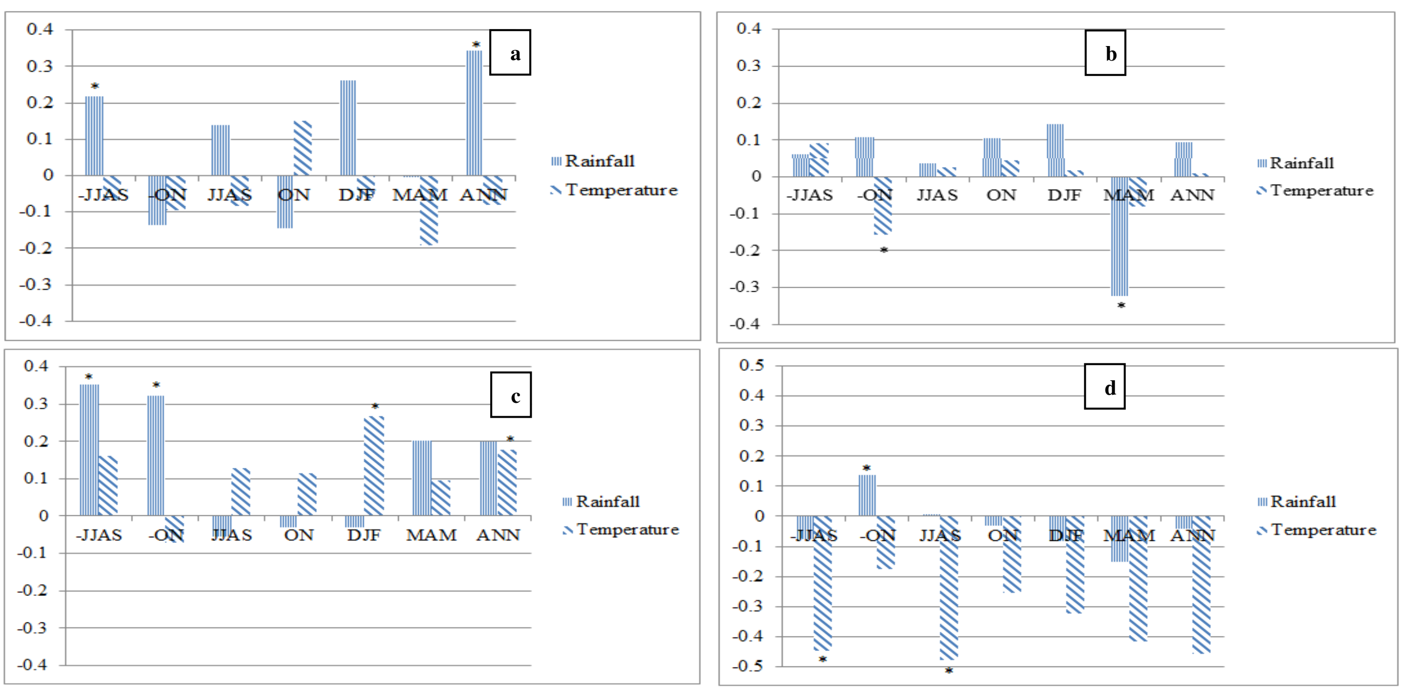
+ Value derived from ring width index, * Value derived from mean vessel area index

Ring width Index and rainfall: The ring width index chronology of all the four sites showed significant correlation with the previous year south west monsoon, previous year north east monsoon, summer and annual rainfall at different sites. The rainfall received at two monsoons and total annual rainfall shows significant positive relationship with tree ring width variations[9]. The previous south west monsoon has the highest significant correlation (0.354) with the Ponganamkadu ring width index chronology followed by Elanad chronology (0.218). The chronologies from Ponganamkadu and Karikadam were correlated with previous north east monsoon with correlation values of 0.324 and 0.139 respectively figure-4.

Positive significant correlation between ring width and previous south west monsoon at two of the study sites suggests rainfall has got a key role in the radial growth of teak. Also it can be seen rainfall during north east monsoon of the previous year has almost the same correlation of previous south west monsoon with growth in two study sites. Dendroclimatological studies from peninsular region of India using teak had showed that rainfall received in previous southwest and north east monsoons and that during current year monsoons has significant relation to teak growth[21,22]. Similar observations were also made by Shah et al.[12] and Ram et al.[13] who found significant relationship between monsoon rainfall and radial growth of teak from central India. This indicates that the moisture stored in the soil from both of the previous monsoons are important for current year growth and development of teak trees growing in study sites.

The ring width chronology from Ponganamkadu has highest correlation with previous north east monsoon (0.324). The high rainfall received in this site might be helping in the fast movement of stored nutrients that help in the commencement of growth in the current growing season. The summer (March-May) rainfall was negatively correlated (-0.321) only with the Vazhani ring width index chronology, while other sites had no significant relationships. The negative correlation of ring width chronologies with summer rainfall might be due to poor net rateof photosynthesis, apparently due to higher evapotranspiration in the study sites[22]. Generally during summer season in Kerala, rainfall is least in the given year, but temperature goes up to the maximum. So, even though there was increased rainfall, the prevailing high temperature during March-Mayshould have caused stress for waterin trees due to high evapotranspiration rates[12]. The annual rainfall was correlated with only Elanad ring width index chronology and no other chronologies. Ram et al.[13] has also reported significant association between annual rainfall and ring width index.

Ring width index and temperature: The temperature did not show much association with ring width index chronologies of study sites when compared to rainfall. The chronology was negatively correlated with previous October-November temperature at Vazhani (-0.156) and with previous June-September temperature (-0.446) and current June-September temperature (-0.477) at Karikadam figure-4. Teak grown in Bori, central India[13] showed negative correlation with current year's October-November temperature and annual temperature but Margaret and Bernard[23] reported that the best growth forecasters of teak grown in Puerto Rico are temperature in July and November months. Increased evaporation and transpiration caused by temperature rise may decrease topsoil moisture and restrict tress from obtaining it in subsequent growing season. In addition, higher temperature can be preventing effective photosynthesis and respiration to take place[1]. There is an optimum range of temperature for net photosynthesis and it depends upon season, site, moisture, both light availability and intensity[1] in which tree gives good growth and variation from that optimum range might have resulted in the negative correlation of temperature with ring width index experienced in the study sites. The Ponganamkadu ring width index chronology had significant positive correlation with December-February (0.270) and annual temperature (0.179). Earlier studies have suggested that current March temperature had positive effect on the growth of teak trees and annual temperature had negative influence respectively[22]. The results of the present study are different from early reports which might be due to soil moisture already present in the site.



*significant at 5% level; -JJAS: Previous south west monsoon; -ON: Previous north east monsoon; JJAS: Southwest monsoon; ON: North east monsoon; DJF: Winter; MAM: Summer; ANN: Annual

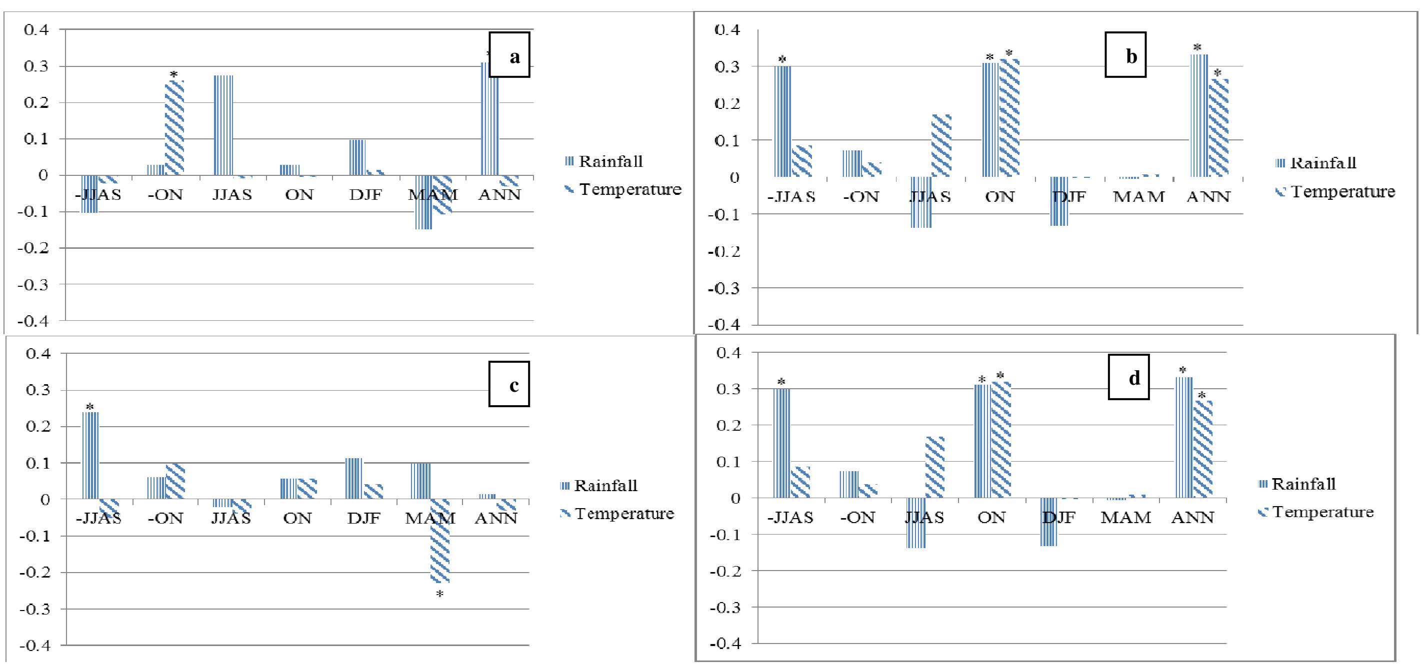
Figure-4

Correlation betweenring width index and climate during different seasons at(a) Elanad; (b) Vazhani; (c) Ponganamkadu and (d) Karikadam.

Mean vessel area index and rainfall: The mean vessel area index (MVA) chronology of all the four sites had significant correlation with the previous year monsoons (both south west and north east) and annual rainfall figure-5. The MVA chronology had significant positive correlation with previous year south west monsoon at Ponganamkadu (0.240) and Karikadam (0.300). North east monsoon showed correlation with Elanad (0.311) and Karikadam (0.310) MVA chronologies. Also, the annual rainfall was significant positively correlated with Elanad, Vazhani and Karikadam chronologies. The findings agree with the views of Shah et al.[12] who proposed that rainfall received during north east monsoon (October and November) of the previous year and April of the current year is an important factor for the development of vessels in early wood region of annual rings in teak. The results of this study deviates from the findings of Pumijumnong and Park[24]. They found that vessel area of the whole annual ring have negative correlation with April rainfall of current year and positive correlation with May rainfall also of the current year. In some oak species also the early wood mean vessel area was observed to be smaller in drought years[25].

The mean vessel lumen area is an indicator of the water availability status of the tree at the time of cell differentiation[26]. It is during summer (March) the early wood vessels of teak start their development and this process continues till start of south west monsoon (June) and when it is beginning of north east monsoon (October) the xylogenesis stops completely. Good reserves of moisture present in soil at the commencement of the summer/dry season is a positive influence on the physiological processes of the tree during subsequent growing season[27]. The stocked energy of the previous year's growth and water availability at the root zone before the growing season are influencing factors in the growth of teak trees and also they are important for the development of vessels in teak.

Mean vessel area index and temperature: The mean vessel area indices of the study sites showed significant positive correlation with previous October-November temperature, March-May temperature, October-November temperature and annual temperature figure-5. The MVA index chronology has significant positive association with previous October-November temperature at Elanad (0.292) and Vazhani (0.260). The index has significant positive correlation with October-November temperature (Karikadam; 0.320) and with annual temperature (Karikadam; 0.266). Significant negative correlation was shown between summer temperature (-0.228) and Ponganamkadu mean vessel area index chronology. In *Castanea sativa*, mean monthly temperatures during March and June and mean vessel lumen area were closely correlated[28]. Increased temperature during pre-monsoon months (March-May) was found to have an important role in the initiation of cambial activity[29]. The relationship between previous year north east monsoon and north east monsoon with mean vessel area as observed in this study show deviation from the earlier studies. There is not so clear association of temperature and increased vessel area in this study and it might be due to the fact that vessel development and wood formation is regulated by a complex system in which there is constant exchange of internal plant and external environmental signals[30].



*significant at 5% level; -JJAS: Previous south west monsoon; -ON: Previous north east monsoon; JJAS: Southwest monsoon; ON: North east monsoon; DJF: Winter; MAM: Summer; ANN: Annual

Figure-5

Correlation between mean vessel area index and climate during different seasons at (a) Elanad; (b) Vazhani; (c) Ponganamkadu and (d) Karikadam

Conclusion

In the study presented we found both temperature and rainfall influenced ring width whereas temperature, rainfall during summer influenced both ring width and MVA. There are significant responses of ring width and mean vessel area (MVA) to climate in teak and these parameters have prospect for climatic reconstruction of the study sites if older samples are available. These efforts will help in understanding past monsoon variability and help in climate-growth predictions. The significant relationship between MVA of teak and rainfall of the study sites suggests that it can be used as a proxy for reconstruction of precipitation data of south west and north east monsoons in Kerala. Short period tree ring analyses of teak from Kerala have great potential in sustainable management of teak plantations as it reveals new information about age, climate and locality related variability in the growth of teak.

Acknowledgements

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