Climatic reconstructions using dendo-climatological techniques offer a possibility for adding information both spatio-temporal and temporal coverage which is crucial for understanding the contemporary climatic variability, change in climatic and atmospheric conditions (CO$_2$, temperature and rainfall) which lead to increased nutrient deposition and recovery after major disturbances. To understand the effects of global change on tropical forests have been primarily focused to predict the fate of globally important ecosystems, inform international policy makers, guide conservation and management efforts. Dendroclimatology means branch of dendrochronology (Dendro - tree and chronology - time) science of reconstructing past climate by use of tree rings in temperate, tropical and subtropical regions. It determines the age of trees, biological rotation ages, rates of radial growth and the influences of regional climate variables on tree growth.

Vessel is a constituent of xylem and primary meant for the conduction of water from soil to leaves especially in hardwood. The vessel, size, number, distribution in a tree ring, either early wood or late wood portions, or in the entire ring have been recognized as significant parameters in ecology and environmental studies. A large number of tropical hard wood trees produce growth rings but only few taxa among these seem to have the characteristic, where by tree-ring sequences was datable exactly to their year of formation. Despite the dendo-chronological potential, there is a notable spatial gap in the regional coverage of dendroclimatic reconstructions in the Nilambur forest division, Kerala where only limited dendro-climatological research has been completed. Dominated by monsoon climate, Kerala could form an important site for understanding tree-growth responses to climate. Also the usefulness of teak for dendroclimatic reconstructions like rainfall and ENSO (El-Nino Southern Oscillation) index has already been reported by several workers.

Teak (Tectona grandis L.F.) belonging to the family Lamiaceae and native to south and south-east Asia, mainly India, Indonesia, Malaysia and Myanmar, but is naturalized and cultivated in many countries, including those in Africa and the Caribbean. It is found in a variety of habitats and climatic conditions from arid areas with only 500 mm of rain per year to very moist forests with up to 5,000 mm of rain per year. Typically, though, the annual rainfall in areas where teak grows averages 1,250-1,650 mm with a 3-5 month dry season. Teak is a yellowish brown timber with good grains, texture and multipurpose uses such as furniture, boat decks etc. Many trees in the tropical forests of the Indian subcontinent are known to produce growth rings. Among the trees with growth rings, teak exhibits datability of growth rings to the formative year. Annual nature of growth rings in teak trees was established by Berlage and Chowdhary; Bhattacharyya et al.; Borgaonkar et al.; Shah et al.; Ram et al.; Ram et al. have shown that the variations in ring-widths of teak trees from India can be used in reconstruction of the past climate. Pattern of radial growth in trees depends largely on the climatic factors and anatomical characteristics of the vessel as well ring width in teak (Tectona grandis L.) grown as plantation from Edakkode, Edavanna Forest Range, Nilambur North forest division, Kerala, India. Indeed, in the present study, ring width, mean vessel area (MVA) were measured and crossdating, chronology building, standardization and dendroclimatic analysis were done. The results suggested that characteristics of teak, ring width and mean vessel area, studied were influenced by the monthly temperature and rainfall. However, seasonal climate which influenced ringwidth were of previous southwest monsoon rainfall and north east monsoon negatively influenced mean vessel area.
conditions of different localities. Reconstruction of past rainfall using ring-width variations involves finding a response function for tree growth, which in turn involves finding regression coefficients between ring widths and monthly rainfall of the corresponding year. From the above mentioned studies, the response of teak growth to the ambient climatic parameters (mainly rainfall) appears to be site specific. However, the relationship between ring-width and climate is complicated by a variety of non-climatic parameters. The present investigation focused on analysis of the tree-ring chronologies in teak grown as plantations, find out whether any significant relationship exists between climate and ringwidth as well as Mean Vessel Area (MVA) of teak in Edakkode plantation, Kerala.

MATERIAL AND METHODS

The present investigation was conducted to develop tree-ring chronologies from plantation-grown Teak (Tectona grandis) of Edakkode plantation (N: 11°18′20″ and E: 76°11′46″), Edavanna Forest Range, Kerala (Fig.-1) and also to understand the relationship between climate and tree growth. Nilambur North Forest Division has total area of 29,805 ha out of which 1816 ha under teak plantations which has 47 teak plantations of varying ages and sizes (KFRI, 2005).

Climate of the experimental site: Nilambur North Forest Division features a tropical monsoon climate. The summer season from March to May is followed by the southwest monsoon rainy season from June to September and then from October to November north east monsoon rainy season. The winter season is from December to February. Nilambur has significant rainfall during most months, with a short dry season. The mean temperature was recorded 27.7°C and mean precipitation 2666 mm.

Sample collection: The samples were collected from tree stumps/logs after final felling of the plantations. A portable chain saw was used to cut the basal discs from the left over stumps/logs (Fig.-2). Total 10 samples were collected from Edakkode plantation which comes under Edavanna Forest Range, Nilambur North Forest Division, Kerala established on 1949. Here, from each tree, one basal disc was collected (Fig.-2).

Preparation of samples: The upper surface of the basal discs collected from the field was first planed with a portable hand planer to make the surface even. Then the disc surfaces were smoothened with sand papers of grit sizes 60, 80, 150, 220, 320, 400 in selected 3 to 4 radii successively to expose the growth rings for measuring the ring width. For measuring the mean vessel area selected radii were further sanded with sand paper of grit sizes 600, 800, 1000 and 1500 successively. The samples were then washed with a water jet to make vessel lumen clearly visible.

Measurement of ring width: The growth rings were counted and cross matched on three to four radii on each disc from specific sites after polishing. Live images of the selected rings across the radius were viewed on a computer screen using digital camera attached to a stereomicroscope (Motic) and ring widths were measured using tree ring measurement platform LINTAB-6. The ring widths (earlywood, latewood, total wood) of each year obtained from the different radii were digitally recorded in 0.001 mm precision using TSAP Win software.

Measurement of mean vessel area: Four radii were selected from each sample to measure mean vessel area of earlywood, latewood and total wood in each annual ring. Macro images of the selected rings with 20x zoom were captured across the radius using a digital camera fitted to a stereozoom microscope (Motic, Fig.-3) and vessel area was measured and digitally recorded using the image analysis software Moticam Image Plus 2.0.

Cross dating: The selected radii were cross dated using the procedures suggested by Stokes and Smiley. Cross dating of tree ring data is used for verification of series and the elimination of possible errors and to find the correct dated position in time. After measurement, cross dating is an important step before analysis of time series. Elimination of measurement errors like removal of false rings and insertion of missing rings were done.

Standardization: For each tree, the series of raw data were detrended and standardized using ARSTAN software. This was done in order to remove biological and geometrical trends (age and size related growth trends). A cubic smoothing spline was used with a 50% frequency response cutoff of 2/3 mean series length to maintain the high-to-medium frequency response to climatic variability. Autoregressive modeling was performed on each detrended ring-width series to remove most of the first-order autocorrelation, and the prewhitened series were finally averaged using a biweight robust mean to obtain residual chronology. Standard version of the chronology was selected and used for further analysis.

Dendroclimatic analysis: The relationship between climate and tree growth was examined for the period 1949-2012 using
high resolution, 0.5° x 0.5°, grid data obtained from CRU TS V. 3.21 (Harris et al., 2014). Correlation analysis of tree ring data (ring width index and mean vessel area index) versus monthly, seasonal rainfall and monthly, seasonal temperature using the statistical package DENDROCLIM was performed\(^\text{31}\). For the analysis a dendroclimatic year of 18 months starting from June of previous year to December of current year was used. Seven seasons were defined as previous south west monsoon (pJJAS), previous north east monsoon (pON), south west monsoon (June-September; JJAS), post-monsoon or northeast monsoon (October-November; ON), winter (December-February; DJF), summer (March-May; MAM) and annual (Ram et al., 2008). Bootstrap correlation and response function analyses were carried out with moving intervals to find out tree growth - climate relationship.

### RESULTS AND DISCUSSION

Tree-ring based regional reconstructions indicate noteworthy variations in dry/wet and warm/cold epochs of spring and summer climate during the past 300 years, but trees throughout the region do not show any direct impact of monsoon rainfall\(^\text{32-33}\). The central and peninsular Indian region is strongly influenced by summer monsoon rainfall; however, more than 75% of total rainfall was received during the south west monsoon (June-September, JJAS). However, little attention has been given to the study of the relationship between climate and ring width as well as MVA of teak. In this terrain, most of the precipitation runs off, causing moisture stress at the root zone of trees, particularly in years of deficient rainfall. The teak tree-ring data presented here are from midland moist deciduous area.

**Ringwidth and climate:** At Edakkode the current February rainfall had a negative influence (\(r=-0.438\)) on standard earlywood chronology while rainfall in current October had a positive influence (\(r=0.368\)) on standard latewood chronology (Fig.-3). Analysis of tree-growth and climate relationship at Mundagod, Karnataka by Sinha et al.\(^\text{34}\) suggested April rainfall of the current year and October rainfall of the preceding year had negative influence on ring width. Analysis of tree growth and climate relationship suggested that the rainfall during March of the current year and October of the preceding year has positive influence, whereas April rainfall has negative influence on the growth of teak at Chandrapur, Karnataka\(^\text{34}\). Regarding the monthly temperature the positive influence was with earlywood and June temperature (\(r=0.331\)) and negative influence with totalwood and PJuly temperature (\(r=-0.372\)) (Fig.-4). Current July and November temperature and previous November temperature were the best predictors of growth of teak at Rio Abajo, Puerto Rico\(^\text{35}\). The principle of limiting factors is important to dendrochronology\(^\text{36}\).

The range of rainfall reported for teak in its native habitat in Southeast Asia is 1200-3400 mm\(^\text{27}\). The 3000 mm per year of rainfall at Nilambur appears to be sufficient for teak during most of the year, so mean temperature can become the limiting factor in some micro sites. In seasonal climate pJJAS and DJF temperature negatively influenced latewood (\(r=-0.479; r=-0.465\)) also the rainfall of same seasons had positive influence on ringwidth (\(r=0.420; r=0.374\)) (Fig.-5). Dendro-climatological 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\(^\text{34, 37-38}\). Teak from Central India also shows a signal of monsoon (JJAS) rainfall useful for reconstruction\(^\text{18}\). Buckley et al.\(^\text{39}\) have demonstrated a decadal scale drought history for Thailand based on a multi-century teak chronology. They suggest that the variability in annual growth of teak is dependent on soil moisture availability and rainfall during the monsoon season. Monsoon and annual rainfall of Kerala have a significant positive relationship with teak tree ring chronologies from Kerala\(^\text{40}\). The
Fig. 3: Correlation between monthly rainfall and standard ringwidth index chronologies at Edakkode

Fig. 4: Correlation between monthly temperature and standard ringwidth index chronologies at Edakkode

Fig. 5: Correlation between seasonal climate and standard ringwidth index chronologies at Edakkode
Fig. 6: Correlation between monthly rainfall and standard MVA index chronologies at Edakkode

Fig. 7: Correlation between monthly temperature and standard MVA index chronologies at Edakkode

Fig. 8: Correlation between seasonal climate and standard MVA index chronologies at Edakkode
negative correlation with previous monsoon may be due to the carry-over effect of moisture at the root zone. Higher rainfall during any particular year helps in maintaining the normal growth of the tree for the next two-three years even though the rainfall during these years could be less\textsuperscript{15}. The reverse process is also true when very less rainfall during any particular year creates moisture stress condition at root zone which may continue in the next one-two years resulting in below normal tree growth in successive years.

**Mean Vessel Area and Climate:** In Edakkode the pNovP had positive effect on totalwood ($r=0.550$) and June P had negative effect on earlywood ($r=-0.371$) (Fig.-6). Moisture availability is the most important climatic variable in developing the early wood vessel of an annual ring\textsuperscript{41}. They found that vessel area of the total ring was negatively correlated with current April rainfall and positively correlated with current May rainfall. The mean lumen area of earlywood vessels in oak was smaller in drought years\textsuperscript{42}. The vessel lumen area is an indicator of the water availability at the time of cell differentiation\textsuperscript{43}. From these records, it appears that early wood vessel development in teak starts around March and ceases during June, and by the first week of October there is no wood formation. The increased soil moisture at the beginning of the dry season also favours the physiological processes of the tree during subsequent growing season\textsuperscript{44}. November temperature had positive effect on latewood ($r=0.445$) and June temperature negatively affected earlywood ($r=-0.381$) (Fig.-7). In chestnut, mean vessel lumen area is mainly negatively related to temperature in the current March and to some extent, in February (i.e. just before the beginning of the growing season). Ring-porous trees like chestnut begin developing the first earlywood vessels just before or at the time of bud break\textsuperscript{45}, earlier than the resumption of photosynthetic activity.

Thus, the beginning of earlywood formation is supported by the mobilization of reserves stored during the previous growing season\textsuperscript{46}. For seasons DJF temperature had positive correlation with latewood ($r=0.504$) while ON rainfall negatively influenced latewood ($r=-0.445$) and totalwood ($r=-0.462$) (Fig.-8). The findings agree with the views of Shah et al.\textsuperscript{18} who suggested that rainfall during October and November (north east monsoon) of the previous year and April of the current year is the moisture availability at the root zone before the growing season is favorable in the tree's growth process. Stored energy of the previous year's growth and water availability at the beginning of the growing period are also important for the development of teak tree vessels. Cambial activity studies by Priya and Bhat\textsuperscript{44} showed that the pre-monsoon showers break the cambial dormancy and higher amount of rainfall contributes to the greater amount of wood formation. The authors also pointed out concurrence of the period of the highest cambial activity and the period of the highest rainfall.

**CONCLUSION**

Wood anatomical features measured viz., tree ring width, vessel area have often proven to be of ecological value and adds novel information to understanding the chronological variability in the growth of teak with changes in climate. The result shows that characteristics of teak, ringwidth and mean vessel area, studied were influenced by the monthly temperature and rainfall. However, seasonal climate which influenced ringwidth were of previous southwest monsoon rainfall and north east monsoon negatively influenced mean vessel area. This study deals that vessel as well ring width 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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**REFERENCES**

Fig. 2.(1). Teak plantation; B. Cutting of discs from felled tree at Edakkode; and C. Separate disc from felled tree

Fig. .(2). Polishing of wooden basal disc; and B. Measurement of ring width using tree ring station and stereo microscope