TREE GROWTH CLIMATE RELATIONSHIP IN PLANTATION TEAK (*Tectona grandis* L. f.) GROWN IN THRISSUR DISTRICT, KERALA

By

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(2010-20-117)

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR - 680 656

KERALA, INDIA

2015

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THESIS

Submitted in partial fulfilment of the requirements for the degree of

B.Sc. –M.Sc. (Integrated) CLIMATE CHANGE ADAPTATION

Faculty of Agriculture

Kerala Agricultural University

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR - 680 656

KERALA, INDIA

2015

DECLARATION

I, hereby declare that this thesis entitled **"Tree growth climate relationship in plantation teak (*Tectona grandis* L. f.) grown in Thrissur District, Kerala"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Tree growth climate relationship in plantation teak (*Tectona grandis* L. f.) grown in Thrissur District, Kerala"** is a record of research work done independently by **Miss.Gayathri Asok (2010-20-117)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Associate Professor and Head,
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CERTIFICATE

We, the undersigned members of the advisory committee of **Miss. Gayathri Asok (2010-20-117),** a candidate for the degree of BSc- MSc (Integrated) Climate Change Adaptation agree that the thesis entitled **"Tree growth climate relationship in plantation teak (*Tectona grandis* L. f.) grown in Thrissur District, Kerala"** may be submitted by Miss. Gayathri Asok, in partial fulfillment of the requirement for the degree.

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GAYATHRI ASOK

DEDICATED TO MY PARENTS,
AND BROTHER

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CHAPTER 1

INTRODUCTION

Dendroclimatology is the science of determining the past climate from recent climate growth relationship (Fritts, 1976).Tree rings are wider when conditions favour growth and narrower during unfavorable conditions. Using tree rings, many local climates for hundreds to thousands of years had been estimated. By combining multiple tree-ring studies (sometimes with other climate proxy records), scientists have estimated past regional and global climates. Tree ring research can also provide great insights into the mechanisms of climate change (Briffa *et al.,* 2004).

Teak (*Tectona grandis* L.f.) found in the natural forest and plantations of Kerala, being a ring porous species (early wood distinctly different from late wood) is ideally suited for dendroclimatological studies. Teak is a hard wood timber species which is widely distributed in the central and peninsular parts of India. Teak usually grows in the 800-2500 mm rainfall regime and from sea level to an altitude of about 1200 m. It grows well in alluvial soils, fairly moist, warm, tropical climate with soil pH ranging from 6.5 to 7.5. Teak is a ring porous species, useful for dendroclimatological studies because it shows distinct annual growth ring pattern.

Annual growth rings in trees indicate the age and growth rate of rings and they reflect the change of the regional climate. Tree rings have been used in various applications to reconstruct past climates as well as to assess the effect of recent climatic and environmental changes on tree growth. About twenty five per cent of tropical tree species produce growth rings, majority of them being softwood species growing within the tropical regions. Many trees in the tropical forests of the Indian subcontinent are known to produce growth rings (Gamble, 1902). Seasonality in the growth rate of trees driven by variability in the climatic factors can result in well-defined growth rings in trees.

Individual tree rings record contemporary climatic signatures and thus provide an opportunity to decipher the variation in climatic parameters for a duration equivalent to the life span of the tree (Managave *et al*., 2010).Tree rings play an important role in global climate change studies with high resolution and reliability, Tree-ring chronologies have been widely used for reconstructing climatic variability in the recent past years (Schweingruber, 1996).

The present study focused on the analysis of tree ring chronologies in teak grown at Vazhani in Machad range, under Thrissur forest division with the following objectives

1. To study the relationship between climate and tree ring width

2. Evaluate the tree-ring chronologies of teak to find out their dendroclimatic potential.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Dendrochronology has its own importance to investigate the tree ring growth variability and its interaction with climate change. Mainly these studies have been implemented at the site level for tree ring chronology in teak. Hence the present study tries to evaluate the relationship between climate and tree ring width of teak with dendroclimatic potential.

2.1 Dendroclimatological studies

The science of reconstructing past climate by use of tree-rings is known as dendroclimatology which is a branch of the more general discipline of dendrochronology (Fritts, 1976). *Tectona grandis* is one of the tropical species that shows clear growth rings and suitable for climatic analysis (Chowdhury, 1964; Detenne, 1989; Bhattacharya and Shah, 2009). So it is widely used in the dendrochronological studies in the tropics.

According to Fritts (1976) dendrochronology deals with the study of chronological sequence of annual ring (tree ring) and its application on various aspects. It has become a valuable tool in forest resource inventory as it provides long term information about the cause and effect which would be very useful in evolving the judicious forest management practices. The annual growth rings in trees indicate the age and growth rate of the trees. 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. 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.

The tree ring analysis since long has been used as a dating tool in archeology subsequently applied in climatic studies and since last several years it has gained also importance in studying the impact of various environmental factors other than climate also on tree growth (Hughes *et al.*, 2002).

Teak (*Tectona grandis*) is one of the few tropical species showing distinct and reliable growth rings and holds potential for reconstructing monsoonal precipitation over India. Annual nature of growth rings in teak trees was established by D'Arrigo *et al*. (1994), Buckley *et al*. (2007), Ram *et al*. (2008) have reported reconstruction of past climate, especially rainfall, using variations in ring-widths of teak.

The climate phenomena seen through tree rings have spatial scales from a few hectares to a hemisphere, and temporal scales from the few hours of an ice-storm, through decades of drought, to centuries of changed global atmospheric circulation. Climate has been used as a source of explanations for changes in the size and state of tree rings, and as a predictor of future tree-ring growth (Szeicz and MacDonald, 1995)

D'Arrigo *et al.* (1997) reported the use of Khasi pines and Merkus pines from northern Thailand for dendroclimatic research. In their study they found that, Khasi pine was shown to have fewer problems with crossdating, than Merkus pine. Another study conducted by Pumijumnong and Wanyaphet (2006) in the same region found that Merkus pine chronology had a positive response to April and May rainfall.

Mann *et al.* (1999) reported that the tree-ring chronologies have been widely used for reconstructing climatic variability in the Northern Hemisphere. The reconstructions based on tree ring can offer extended records to understand long term variability of climate parameters. Thus it provides a great insight in climate change.

Pandey (2002) mentioned in his study about tree rings that it has been used in various applications to reconstruct past climates as well as to access the effect of recent climatic and environmental changes. And he also reported that the temperature can influence the tree ring growth.

Esper *et al*. (2002); Briffa *et al.* (2004) cited that the tree rings have been used in various applications to reconstruct past climates as well as to access the effect of recent climatic and environmental changes on tree growth.

Gajewski and Atkinson (2003) observed that northern tree line dendroclimatological studies sometimes reveal a mixed climate signal with temperature and precipitation.

Buckley *et al.* (2005) used Merkus pine from India and Thailand to analyze relationships with global surface temperature, found that the greatest influence on growth resided with sea surface temperature in the tropical Pacific and Indian Ocean sectors. The study also constitutes further exploration of the response of Merkus pine to climate for an area that has not been previously studied.

(Andreu *et al.*, (2007), D'Arrigo *et al.*, (2008), Tardif *et al.*, (2003), and Buntgen *et al.*, (2006)) reported that common signal strength of tree growth and climate association between chronologies of various sites can vary through time.

Pisaric *et al*. (2009) reported that dendroclimatological studies in the central Northern Thailand indicate that large, regional-scale climate patterns and synoptic level climate change are the primary drivers of the area's tree growth. Compared to the extent of American and European dendroclimatological records, the area has relatively short and sparsely distributed dendroclimatological studies (Szeicz and MacDonald, 1996).

Speer (2010) cited that in order to have a better understanding of climatic variability, dendroclimatology relies on several assumptions. The fundamental assumption is the principle of uniformitarianism, which states that physical and biological processes that link present day environmental processes with present day tree growth have been in operation in the past.

Wigley *et al.* (1984) mentioned that EPS (Expressed Population Signal) is a measure of the correlation between the mean chronology derived from the core samples and population from which they are drawn. A value of 0.85 was put forward as a reasonable threshold. SNR and EPS show the usefulness of the chronology for past climate reconstruction. Strength of signal between trees (common variance) was computed by calculating the signal-to noise ratio.

Ram *et al*. (2011) proposed Signal to Noise Ratio of 8.1 recorded at Allapalli site. A study conducted by Ugulino *et al.* (2014) also observed the high Signal to Noise Ratio of 7.438. It was found that Signal to Noise Ratio in Dandeli is 5.90 and Shimoga is 2.69. The value of SNR is moderately high for both chronologies but the highest value of SNR is found at Dandeli (Deepak *et al.,* (2010).

Shishkova and Panayotov (2013) mentioned that mean ring width is 121(mm) in Rhodopes. A similar study conducted by Deepak *et al*. (2010) observed that the average ring width of Dandeli (2.15mm) and Shimoga (3.10mm). He also reported that correlation with the average monthly temperature series was statistically significant and negative ($r > 0.273$) for the months from June to September of the year prior to growth.

(Ram *et al.*, 2010) reported that annual variations of teak growth in central India have been demonstrated and found to be highly influenced by the moisture index. Pant and Borgaonkar (1983) observed the response of teak to rainfall in the rainy season for India. In this study they investigated the dendroclimatic potential of teak.

2.2 Dendroclimatological studies in temperate regions

Hughes *et al.* (2002) showed that Scots pine in Scotland has a temperature dependent growth at higher elevations.

Around 20 years ago, dendroclimatic studies were discontinued using trees in the British Isles because it was believed that they were less sensitive to climate than those which live under more critical conditions. The limited usefulness of oak as a climate proxy had previously been demonstrated by Briffa (1984).

Cook (1987) and Juknys *et al*. (2002) suggested that the average monthly temperature is usually treated as the main factor that influenced tree ring formation. La Marche and Fritts (1971) and Colenutt and Lukman (1996) also reported that annual increment growth of *Pinus cembra* was influenced mainly by summer temperature.

The influence of precipitation, saturation deficit, relative humidity, and temperature on the growth of P*inus sylvestris* growing on 21 different sites in Germany, was investigated by Spurk (1997). A significant influence of precipitation, followed by saturation deficit and relative humidity was observed. The influence of climate partially increased from early wood to late wood caused by drier soil condition in the course of the year (Briffa 1998b).

A study in Alaska has noticed that contrasting climate responses could occur even within a site, highlighting the need for investigation of tree-growth and its climate response of individual trees of a given site prior to building a chronology (Wilmking *et al.*, 2004). Only very limited knowledge is available on tree-growth variability and climate–growth responses for individual trees.

The incomplete distribution of tree-ring records in the circumpolar north has limited the understanding of large, regional, and local scale temperature and precipitation patterns over the past several hundred years (Cook *et al.,* 2007).

D'Arrigo *et al.* (2009) reported that the tree-ring records are an invaluable resource for interpreting both the nature of human-induced climate change compared to natural variability, and also for understanding the response of forests to changes in climate. Tree-rings are one of the most widely used proxy data sources in climate reconstructions largely because they provide high resolution climate information due to their annual nature.

According Seo *et al.* (2011) climatic factors are among the main external ones which have been extendedly studied especially in cold and temperate regions of Europe and North America. Most of these studies have been focused on the long term relations of climate-growth based on inter-annual tree ring researches but results of such studies could derive from the intra-annual climate/growth analysis.

According to Jones *et al.* (2012) effects of climatic factors on tree growth are usually determined by analysis of various tree-ring parameters thus focusing on secondary growth. Relationships between climatic factors and height (primary) growth of Scots pine in Finland showed that climatic factors have a strong effect on height growth. Thus height increment of trees also appears as a valuable proxy for climatological studies. Relationships between height growth of Scots pine in two experimental plantations (local provenance and diallel hybridization experiment) in eastern part of Latvia and climatic factors was determined by dendrochronological techniques.

At the northern boreal treeline, tree growth is closely related to summer temperature. Anchukaitis *et al.* (2013) reported that numerous dendrochronological studies, especially those using white spruce at the North American latitudinal tree line, have successfully reconstructed summer climate variability during the past several centuries to millennia. A number of recent studies have shown that rapid warming during the 20th century has caused the previously temperature sensitive white spruce trees to become decoupled from summer temperatures. Trees that previously tracked summer temperature variability are now recording declining trends in growth under theoretically more optimal growing conditions (Briffa *et al.*, 1998a; Porter and Pisaric, 2011).

2.3 Dendroclimatological studies in tropical regions

Gamble (1902) studied growth rings in a large number of tropical trees as annual rings. And he also observed that even in species where the rings were distinct, age determination by counting their growth rings was considered unreliable. It is estimated that about twenty five percent of the total number of tree species produce growth rings.

Eckstein *et al.* (1981) reported that many woody species in tropical and intra-tropical forests, such as Bolivia's, do not form distinct growth rings. The basis of this argument is the belief that cambial activity does not vary throughout the year (Dave and Rao, 1982; Borchert, 1999).

The distribution of natural teak in South Asia (India) and Southeast Asia (Thailand, Myanmar, and Laos) is the most relevant source for dendrochronology in this area. The growth of teak in the Philippines and in Indonesia is thought to have originated from Indian seeds (Lamprecht, 1986).

Teak is a tropical species and found over the entire monsoon belt of south and south-east Asian region. Dendroclimatological studies of teak from India, Myammar, Thailand, Indonesia (Murphy and Whetton, 1989; Pumijumnong *et al.*, 1995; Jacoby and Arrigo, 2006).

In tropical Asia, Pumijumnong *et al.* (1995a) and Buckley *et al*. (2007) have also used ring-width variations of teak for reconstructing past tropical rainfall. The relationship between tree ring-width and climate of tropical regions is complicated by a variety of non-climatic parameters.

D'Arrigo *et al.* (1997) performed dendroclimatic studies on mountain pines in northern Thailand and reported that the oldest Thai pine (*Pinus merkusii*) from PhuKradung existed from 1647 to 1993. The lowest growth rate observed for *Pinus kesiya* occurred in 1979 due to severe drought that year.

Priya and Bhatt (1998) and Jacoby (1989) demonstrated that the cambial activity of teak is influenced by rainfall.

Pumijumnong and Park (1999) cited that tree-ring widths, vessel diameters are used to identify climate data correlations of teak trees. Early results revealed vessel parameters in total rings in early wood correlated negatively with rainfall during the transition period between the dry and wet seasons. Further, vessel parameters were used to reconstruct pre-monsoon temperatures, and latewood vessel parameters exhibited a negative correlation with June temperatures

According to Yadav *et al.* (2002) the climate of the earth is continuously changing due to natural and anthropogenic reasons. For predicting future climate it is imperative to know how climate changed in the past, especially during the past few centuries. High resolution long term climate data during the recent past about 1000 years are needed to understand natural climate variability and the magnitude of human impact on it.

Tree ring research can provide great insights into the mechanisms of climate change (Briffa *et al.*, 2004).

According to Harle *et al*. (2005) tree-ring data offer the opportunity to study growth as well as the impact of variability in the physical environment throughout a tree's entire life span. As a source of proxy climate data, trees possess an unmatched temporal resolution due to forming annual rings.

Trouet *et al.* (2006) reported that dendrochronological studies on long-live tree species have the potential to provide long time series that reflect changes in climate conditions. In the high altitude Al Jabal al Akhdar Mountains of Oman extended *Juniper us excels* a stands exist growing under suitable site conditions. Tree-ring analysis of comparable material has been successfully conducted in both tropical and dry (mountainous) forests in Africa (Couralet *et al.,* 2005; Schöngart *et al*., 2006).

Buckley *et al.* (2005) used pine chronologies from Thailand, India, and Bhutan to examine the relationship between pine tree-ring widths and Asian monsoons. Grid data for the tropical Indian and Pacific Oceans showed ring widths for Thai and Indian pine (*Pinus merkusii*) that strongly correlated with the tropical climate of the Indian and Pacific Oceans, whereas the ring widths in the *Bhutan pine, Pinus wallichiana*, showed strongest association with climates of the northern Pacific and Asian landmasses.

Rodriguez *et al. (2005)* analyzed El Nino events recorded dry-forest species of the lowlands of North West Peru. Short ring-width chronologies of Palo Santo (*Bursera graveolens)* show a well-developed response to the ENSO signal and good inter site correlation. Preliminary isotopic studies in Algarroboalso showed evidence of the 1997-98 El Nino events.

Buckley *et al*. (2007) investigated the growth rings of *Pinus merkusii* from Laos (Lao Peoples Democratic Republic) using three parameters: tree-ring width, early wood width, and late wood width, correlating these parameters with climate data from 13 nearby weather stations in Thailand. All three parameters exhibited significant negative correlation with prior June rainfall and positive correlation with August maximum temperature from the previous year. These three indices also correlated with gridded sea surface temperature in the central and eastern tropical Pacific.

Ram *et al.* (2008) suggested the suitability of teak to understand the past vagaries of monsoon. In teak, local climate effect is more prominent than the regional or global signals. Growth of trees is primarily controlled by the most growth limiting factor; rainfall, in case of teak trees from India. Its widespread distribution in Southeast Asia, a region important for tracking the history of El Nino Southern Oscillation (ENSO), makes it an important candidate for tropical isotope dendroclimatology. (Borgaonkar *et al.,* 2007; Shah *et al.,* 2007) showed that the variations in ring-widths of teak trees from India can be used for the reconstruction of past rainfall.

Managave *et al*. (2010) mentioned that the terrestrial proxies available for climate reconstruction are ice cores, lake sediments, corals, speleothems and tree rings. Among these tree rings have specific advantages: they have a wide geographic distribution, are annually resolved, show a continuous record and are easily dated by ring-counting. Seasonality in the growth rate of trees driven by variability in the climatic factors can result in well-defined growth rings in trees. Individual tree rings faithfully record contemporary climatic signatures hence provide an opportunity to decipher the variation in climatic parameters for a duration equivalent to the life span of the tree.

Cook *et al*. (2010) compiled the Monsoon Asia Drought Atlas (MADA) using tree rings from more than 300 sites across the forested areas of Monsoon Asia (Monsoon Asia regional emphasis of the monsoon over Africa, India, East Asia and South Asia into northern Australia) to reconstruct the seasonalized Palmer Drought Severity Index (PDSI). These results represent outstanding dendroclimatology research in Southeast Asia.

D’Arrigo *et al*. (2011); Pumijumnong (2012) mentioned that teak has shown to be sensitive to climatic variations. False rings may cause measurement errors in tree ring research. The false ring formation is triggered by specific environmental conditions.

Zar *et al. (*2014) reported that the anatomical features of tree rings reflect information about past climatic conditions, and the variation of rainfall patterns from year to year is reflected in tree-ring width pattern.

Ma *et al*. (2014) observed in their study that high temperature would enhance evaporation and further reduce available water at the beginning of the growing season. So that reasons a strongest growth responses to temperature occurred primarily in winter and spring season. In their study they also reported that the temperature strongly correlated with tree growth during the months from January to May. In all other months except October and November, the temperature had positive relationship with growth indices in Himalayan pine (Singh *et al*. (2014).

2.4 Dendroclimatological studies in India

Rao *et al*. (1981) reported that the pattern of radial growth in trees depends largely on the climatic conditions of different localities. 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. It is estimated that about 25 per cent of the total number of tree species produces growth rings. Among these, teak exhibits datability of growth rings in trees to the exact formative year, which is a pre-requisite for dendrochronology.

Pant and Borgaonkar (1983) found that October precipitation, prior to the growth period plays important role on teak grown in moist deciduous forest in Thane region.

Detenne (1989) and Lilly (1977) reported that in tropical and subtropical regions, dendroclimatology is used to a lesser extent than in temperate regions, because of the weaker temperature and day-length seasonality, which results in fewer trees producing distinct annual rings. Sometimes rainfall seasonality can trigger trees to produce annual growth structures in the wood. In southern Africa this is observed in only a few, mainly gymnosperm species, where ring formations are often difficult to identify and interpret.

Jacoby and Arrigo (1989) cited that the growth rings are anatomical structures of the wood that represent one year of their life or other seasonal periods of tree growth. The tree growth can be affected by many factors, environmental factors, physical spaces, edaphic conditions, topographic features and competitive factors. The influence of these factors is recorded in the width and density variation in growth rings, as well as in their anatomical structure.

Guiot (1991) mentioned that south-west monsoon, which accounts for 70–90 per cent of the rainfall over India has been found to be the significant climatic variable controlling growth of teak in the central part of India. This climatic parameter has been selected for the reconstruction through Bootstrapped transfer function. In this analysis the standard tree-ring indices are provided in the predictor matrix to estimate monsoon precipitation. Reliability of the reconstruction models is tested following the usual procedure of calibration and verification (Rao, 1976).

Bhattacharyya *et al.* (1992) reported that teak (*Tectona grandis*. L) is one of the few tropical species showing distinct and reliable growth rings and holds potential for reconstructing monsoonal precipitation over India. Teak has a widespread distribution in south-east Asia – Java, Sumatra, Burma and Thailand – a region important for tracking the history of El Nino-Southern Oscillation phenomenon.

(Sudheendrakumar *et al*., 1993; Priya and Bhat, 1999) mentioned about the relationship between rainfall and teak growth. In their results they found that a higher growth rates during the months of higher rainfall.

Pumijumnong *et al.* (1995) conducted a teak tree-ring study in northern Thailand, and found that teak growth is controlled primarily by Pre-monsoon rainfall that occurs from April to June. According to reconstructed April-to-June rainfall, the previous two decades were moderately wet in northern Thailand.

Yadav and Bhattacharyya (1996) have used teak to conduct studies from a dendrochronological point of view at several sites viz., from dry deciduous forest in Korzi, Andhra Pradesh Upper Narmada river basin in Central India and moist deciduous forest in Thane, Maharashtra (Pant and Borgaonkar, 1983; Bhattacharyya *et al*., 1992).

Dettinger *et al.* (1998) reported that dendrochronology has been particularly useful in the study of inter annual to multi decadal climate fluctuations associated with the interactions of the atmosphere and ocean on very large spatial scales. The regional impacts of these may be seen in changing spatio-temporal patterns of, precipitation or of circulation indices.

(Nobuchi *et al.,* 1996; Borchert, 1999) reported that typical growth sites characterized by seasonality of rainfall and temperature, the wood in *Tectona grandis* is composed of ring-porous growth rings resulting from seasonal fluctuation of cambial activity. In contrast, irrigated young trees have been found to form diffuse porous rings with less or no distinction between early wood and late wood (Priya and Bhat, 1999).

Seasonality in the growth rate of trees driven by variability in the climatic factors can result in well-defined growth rings in trees (Worbes, 1999).

Priya and Bhat (1999) reported that in typical growth sites characterized by seasonality of rainfall and temperature, the wood in *Tectona grandis* is composed of ring-porous growth rings resulting from seasonal fluctuation of cambial activity. In contrast, irrigated young trees have been found to form diffuse porous rings with less or no distinction between early wood and late wood. It can be expected that due to the worldwide distribution of teak plantations in various tropical climates, the pattern of tree ring formation can be diverse. Moreover, while a number of reports addressed the seasonal variation of cambial structure (Rao and Rajput 1999), little is known yet about the environmental factors that affect xylem cell differentiation and growth ring structure.

Tree-ring chronologies have been developed and used for to reconstruct relatively local temperature and precipitation histories at various locations in India (Pant and Borgaonkar 1984; Borgaonkar *et al.* 1994; Bhattacharyya and Yadav 1999; Singh *et al.* 2009).

In peninsular India, where the southwest (SW) and northeast (NE) monsoons are prominent. Teak has been widely analysed and is suitable for environmental and climatic analysis (Bhattacharyya *et al.* 1992; Pumijumnong *et al.* 1995; Yadav and Bhattacharyya 1996; Shah *et al.* 2007; Managave *et al.* 2010).

Margret and Bernard, (2003) recorded average ring width of a 13 year old teak from two different sites of Puerto Rico as 5.33 mm and 5.59 mm. A study conducted by Sinha*et al*. (2011) in 57 year old teak from Mundagod (Karnataka) and 130 year old teak from Chandrapur, (Maharastra) found that average raw ring width were 2.14 mm and 2.97 mm, respectively.

Dendroclimatological investigations were carried out on teak (*Tectona grandis* L. f.) collected from various teak dominant areas in Gujarat. To minimize non-climatic influences on ring growth, only healthy trees with no obvious injury or disease were sampled (Zhu *et al*., 2009).

Deepak *et al*. (2009) reported that the tree ring analysis carried out in teak from two sites of Western Ghats in Karnataka. It has clear and climate sensitive growth rings which are datable to the calendar year of their formation. It is cross matching not only within the radius of the tree but also between trees growing on the same site. It has been found to have good potential to know rainfall patterns, mostly the drought years. The potential of tree rings in understanding rainfall patter of drought years is also explained.

In tropical zones, seasonal patterns of wood growth are generally related to water availability (Bhattacharya *et al.,* 2007 and Shah *et al.,* 2007). Many tropical areas have at least 2 months of arid conditions a dry season or a rainy season with a break in rainfall during mid-season permitting one to use dendrochronological methods developed for temperate zones (Schweingruber, 1988). According to several studies, teak has shown to be sensitive to climatic variations (Die *et al*., 2012 and Worbes, 1995).

D'Arrigo *et al.* (2006) reported that tree ring studies of teak from central Java region showed that rainfall of the previous year's rainy season and during the usual onset month of the current year's rainy season has significant relation to teak. So it indicates that the moisture balance of the soil before the beginning of the next year growing season is important for teak growth. A similar observation was found by Ramesh *et al*. (1989).

Buckley *et al*. (2007) conducted a teak study in the Mae Hong Son province in Northwestern Thailand, establishing that a 448-year-old teak chronology was sensitive to summer monsoon variations. Using variability of teak tree-ring morphology data, which depends on the rainfall and soil moisture conditions and teak chronology data captured two prominent periods of drought: one in the early 1700s (in agreement with coral records from the tropical Pacific), and the second in the mid-1700s (in agreement with the known history of El Nino events).

Borgaonkar *et al*. (2007) and Shah *et al.* (2007) have shown that the variations in ring-widths of teak trees from India can be used in reconstruction of the past climate. The relationship between ring-width and climate is complicated by a variety of non-climatic parameters. Bhattacharyya *et al*. (2007) mentioned that teak is an interesting model for studying the formation of tree rings in the tropics because it typically forms a ring-porous wood structure with distinct annual rings as well as false rings. Annual growth rings of teak can provide information on productivity and age structure of the forest stands, and enable dendrochronological research (Jacoby and Ariggo 1990).

Shah *et al*. (2007) used that teak tree-ring data from Hoshangabad, India to reconstruct the June–September precipitation. This study demonstrated that teak from central India exhibits a strong correlation between the tree-ring index and both regional moisture variations and rainfall during the summer monsoon months. A direct effect of temperature on teak growth was not detected. Thus, teak tree-ring chronologies can be used as a high-resolution proxy to examine past rainfall and moisture conditions in central India. Southern Indian teak up to 523 years old has been discovered. The ring-width variations of this teak are sensitive to the Indian summer monsoon rainfall and the SOI. Periods of low tree-ring growth have been associated with El Nin˜o events since the late eighteenth century (Borgaonkar *et al*, 2010).

Borgaonkar *et al*. (2007) and Ram *et al*. (2008) based on analysis of teak trees from central and southern India, demonstrated significant correlations of ring-width variations with pre-monsoon and post-monsoon climate and suggested a moisture index rather than total rainfall as a major factor controlling ring-width variations. Reconstructing past rainfall and temperature using variations in ring-widths thus requires a good understanding of the relationship between tree growth and climatic parameters during various phases of the growing season (Bhattacharya *et al.,* 2007)

Ram *et al.* (2008) mentioned that high resolution long term climate data during the recent past about 1000 years are needed to understand natural climate variability and the magnitude of human impact on it. Even though limited span instrumental climate records are available they are restricted to few places and cover relatively a short period of time. Dearth of high resolution climatic data for longer periods necessitates finding proxies for the past climate. In this time frame, the tree-rings, with their inter-annual resolution, are globally recognized to be among the best archives of past climate. Terrestrial proxies available for climate reconstruction are ice cores, lake sediments, corals, speleothems and tree rings. Among these tree rings have specific advantages: they have a wide geographic distribution, are annually resolved, show a continuous record and are easily dated by ring- counting.

D'Arrigo *et al*. (2008) investigated the drought history of the area using nine drought-sensitive chronologies collected from Java teak tree rings. Using the teak chronology data, they also reconstructed the stream flow rates for the Citarum River in Java, Indonesia for the period 1759–2006. Decreases in tree-ring width paralleled the reduced stream flow recordings, which are associated with the drought caused by the El Nino Southern Oscillation(ENSO) related warming events in the tropical Pacific and Indian oceans due to positive dipole-type variability

Leonelli *et al*. (2008) demonstrated the potential of multi-species tree-ring chronologies from central Italian Alps to reconstruct glacier mass balance.

Ram *et al.* (2008) found that Moisture Index (MI) during monsoon season (JJAS) and annual scale indicate significant positive relationship from central India. Regional moisture index also show strong positive relationship with tree-ring index during previous year post-monsoon (−ON), which is statistically significant at 1% level. Soil moisture availability at the end of monsoon season plays a vital role in tree-growth processes.

Individual tree rings faithfully record contemporary climatic signatures hence provide an opportunity to decipher the variation in climatic parameters for a duration equivalent to the life span of the tree Managave *et al.* (2010).

According to Sinha *et al.* (2011) tree growth and rainfall during June to August of current year had a positive influence on the growth of teak. He also reported that south west monsoon and the rainfall during October of the previous year plays a major role in growth of teak.

Ram *et al*. (2011) conducted a study to determine the relationship of climate to growth of teak (*Tectona grandis*) from Conolly's plot, South India. Monthly rainfall of Kerala subdivision and temperature data of Kozhikode and Palmer Drought Severity Index around the tree ring sites were used in the dendroclimatic analysis.

Ram *et al.* (2010) reported that Ring-width chronologies of teak (*Tectona grandis*) from three different tree sites in Central India. Correlation between April–September moisture indexes with tree-ring chronologies shows a significant positive relationship for the period 1901–2000.

The annual variations in teak growth in central India have been demonstrated by Ram *et al*. (2010) and found to be highly influenced by the moisture index. And he also reported that ring-width chronologies of teak (*Tectona grandis L.* f) from three different tree sites in Central India. Correlation between April–September moisture indexes with tree-ring chronologies shows a significant positive relationship for the period 1901–2000. Pant and Borgaonkar (1983) also revealed the response of teak to rainfall in the rainy season for India. An attempt has been made to investigate dendroclimatic potential of teak from the central part of India, and any significant relationship existing between climate and a tree-ring chronology of teak from Allapalli, Maharashtra.

Ram *et al.* (2011) developed a ring-width chronology of teak (*Tectona grandis*L.f) from a moisture stressed area in Maharashtra, India. Bootstrapped correlation analysis indicated that moisture index (MI) and Palmer Drought Severity Index (PDSI) showed better performance rather than same year rainfall over the region. Tree-ring variations were most correlated positively with PDSI during different seasons compared with ML Significant strong positive correlation with MI, and negative association with temperature and potential evapotranspiration (PET) were found during previous and current year post-monsoon (ON). This study shows that the moisture availability during the post-monsoon of the previous year has a significant role in the development of annual growth rings. The reconstructed previous year post-monsoon (-ON) Moisture Index for the period 1866-1996 indicates 3.5 and 29.3 years periodicities.

The moisture availability at the beginning of the growing season might have important role in the development of annual growth rings over central India, indicates positive relationship between tree-ring chronologies and winter MI (Ram *et al* 2010). They have also reported that, the positive relationship between tree-growth and MI of prior year post-monsoon which is barely significant at 5% level besides monsoon season. MI index during post-monsoon of prior season play an important role in the growth of teak trees in central India. In this study they found a significant positive relationship between tree-ring width variations and MI as well as the PDSI during post monsoon. This result suggests that the soil moisture availability at the end of monsoon season plays a vital role in tree-growth processes as supported by the study of Palmer (1965) and Pant and Borgaonkar (1983).

Deepak *et al.* (2010) reported that Signal to Noise Ratio in Dandeli was 5.90 and for Shimoga were 2.69. Another study conducted by Babu *et al.* (2015) also reported similar result for Ring Width Chronology of teak in Vazhani, Thrissur district as 6.24.

Ram *et al.* (2011) found that the correlation between tree ring index and temperature showed significant negative relationship during previous and current year of post monsoon.

Accordingly Sinha *et al*. (2011) found that tree growth and rainfall from June to August of current year had a positive influence on the growth of teak. Previous year South West monsoon and rainfall during October played a major role in the growth of teak. A study conducted in four teak growing sites of Kerala *viz*, Pongnamkadu, Vazhani, Elanad and Karikadam, showed that ring width had significant correlation with the previous year South West monsoon (Babu *et al*., 2015).

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

The present investigation focused on tree growth climate relationship in plantation teak (*Tectona grandis* L. f.) grown in Thrissur District, Kerala, The objective was to develop tree-ring chronologies from plantation teak *(Tectona grandis*) at Vazhani of Machad Range in Thrissur forest division, Kerala, to understand the relationship between climate and tree growth. The work was carried out at the Department of Wood Science, College of Forestry, Kerala Agricultural University.

3.1 Experimental site

The study area was located in Vazhani of Machad range, Thrissur forest division. It has a total forest area of 29805 ha out of which 1816 ha are under teak plantation.

3.2 Climate

Thrissur forest division experiences a tropical monsoon climate. There are four seasons; summer (March to May), south west monsoon (June to Septembert), north east monsoon (October to November) and winter (December to February).

3.3 Weather data

Month wise weather data such as temperature (maximum and minimum), evaporation and rainfall over a period from 1983 to 2008 was collected from College of Horticulture, Vellanikkara. The Moisture Index was calculated based on the method given by Thornthwaite (1948).

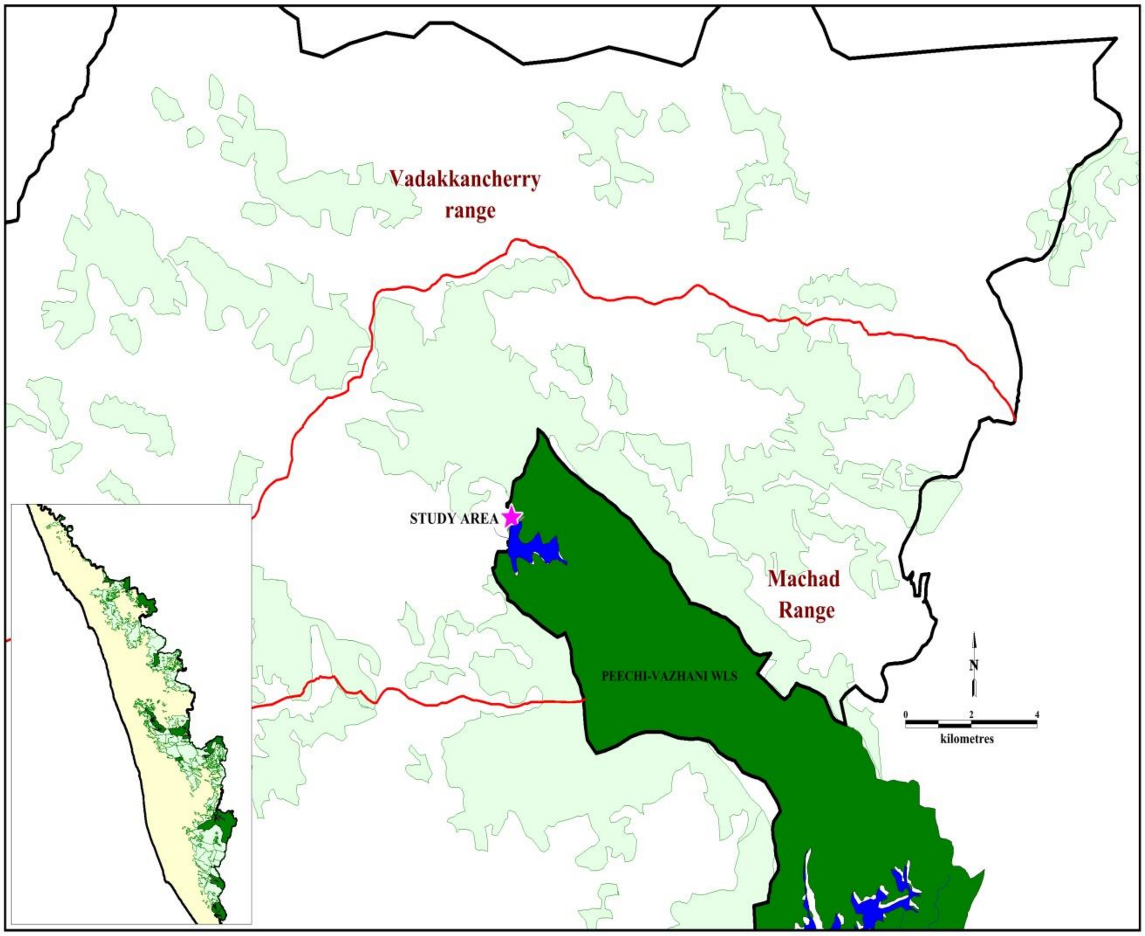


Plate 1. Map showing the study area

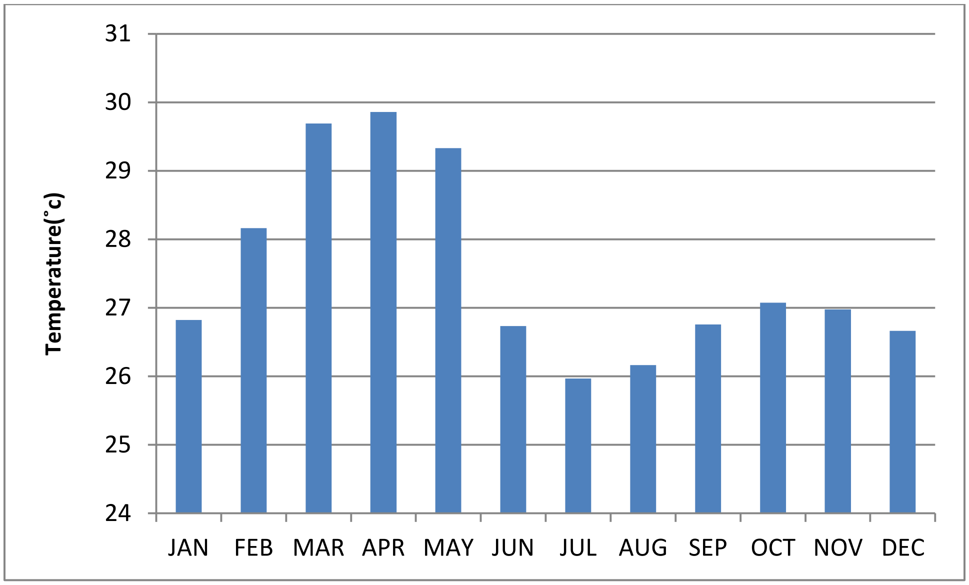


Figure 1. Monthly variation of temperature (1983-2008)

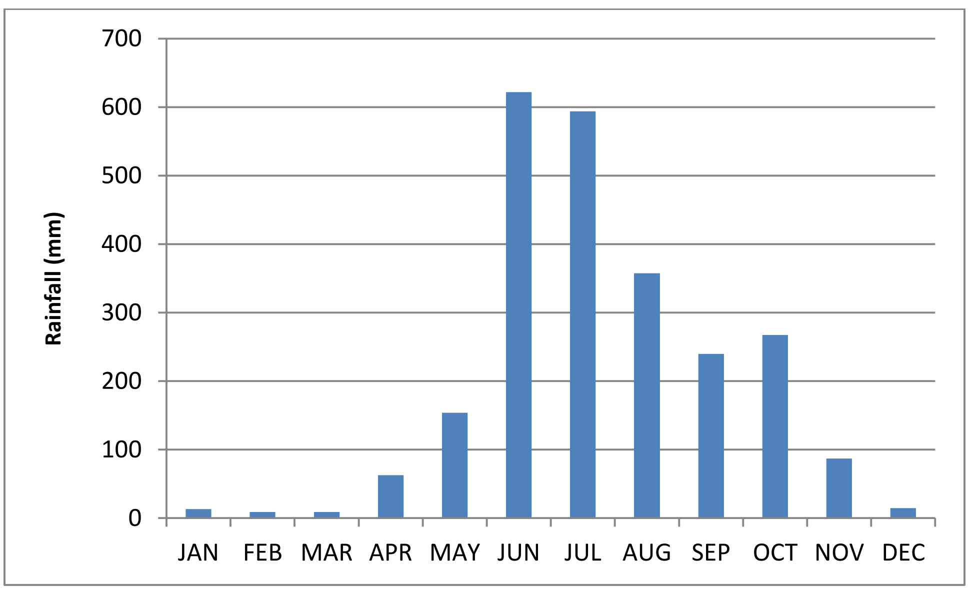


Figure 2. Monthly variation of rainfall (1983-2008)

3.4 Sample collection

The study samples belonging to Vazhani of Machad range were selected from the collection of the Department of Wood Science, College of Forestry.

3.5 Sample preparation

Ten wood samples were selected for the study and these were further sliced with a band saw. In each disc taken, 3 to 4 radius were selected and the surface of discs were smoothened by using different grades of sand papers 80, 150, 220, 320, 400, 800, 600 and thereby exposing the growth rings for measuring the ring width. The preparation of discs and the prepared discs are shown in Plate 1 and Plate 2.

3.6 Measurement of ring width

The growth rings were counted and cross matched within and between the discs that obtained from specific site after polishing. Images of the selected rings were viewed across the radius using a digital camera attached to a stereo microscope (Motic 2) and ring widths were measured using a Tree Ring Measurement Station, (Lintab-6). The average ring width of each year obtained from the different radii was used to construct the chronology using the TSAP Win software. Tree Ring Measurement Station, (Lintab-6) shown in Plate 3.

Plate 2. Preparation of discs to obtain surface for measurement

Plate 3. Disc after preparation

-

Plate 4. Tree Ring Measurement Station (Lintab-6) for measuring ring width.

3.7 Statistical analysis

3.7.1 Standardization

Standardization is a process in which the non-climatic signal of biological and tree disturbances (exogenous) are removed from 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 (Briffa and Jones, 1990) was used for standardization using the statistical package PAST (Paleontological Statistics Version 3.0).

3.7.2Construction of index values and chronology

RIt = Rt/Yt

where,

RIt -Ring Width Index value for the year

Rt -Measured tree-ring datum for the year

Yt - Expected yearly growth obtained from the smoothing spline

3.7.2 Correlation analysis

Correlation analysis of tree ring data (Ring Width Index) against seasonal rainfall and temperature was done using the statistical package PAST (Paleontological Statistics Version 3.0). Seasons were defined as previous south west monsoon (–JJAS), previous north east monsoon (-ON), southwest 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).

The following criteria which are important for dendroclimatological reliability of chronology were calculated using the following equations using Pearson's correlation coefficient (r) and number of trees/radii (N) (Babu *et al.*, 2015).

$$\text{Signal to Noise Ratio (SNR)} = Nr/(1-r)$$

$$\text{Expressed Population Signal (EPS)} = Nr/(Nr+1-r)$$

RESULTS

CHAPTER 4

RESULTS

The present study involved an investigation of tree-ring chronologies from plantation grown teak at Vazhani in Machad range of Thrissur forest division, to understand the relationship between climate and tree growth. The results obtained from the study are presented in this chapter.

4.1 Ring width

The average ring width worked out for the sample for the period 1946- 2008 is presented in Table 1. The average ring width showed a decreasing trend. Mean ring width during the study period was 409.03µm. Graphical representation of the result is shown in Fig. 3. Maximum ring width of 1138.28 µm was observed during the year 1948 and minimum ring width of 110.45 µm recorded in the year 2003.

4.2 Ring Width Index

Ring Width Index for the sample studied was observed to be 1.0079. The Ring Width Index worked out for the sample during the study period is presented in Table 1. A plot of Ring Width Index against time is shown in Fig. 4. Mean Ring Width Index was found to be 1.07.

Table 1. Average ring width and Ring Width Index of *Tectona grandis* at Vazhani

Year	Average Ring Width (μm)	Ring Width Index
1946	1106.06	0.4673
1947	984.76	1.2736
1948	1138.28	1.8241
1949	968.25	1.6288
1950	865.01	0.7739
1951	698.28	1.0122
1952	533.38	1.2085
1953	570.98	-2.7570
1954	486.76	2.4466
1955	598.56	1.1321
1956	750.25	1.3409
1957	623.49	1.3953
1958	528.62	1.6635
1959	709.1	2.7158
1960	409.29	1.6823
1961	471.02	1.5309
1962	557.65	1.1158

Conti…

Year	**Average ring width (μm)**	**Ring Width Index**
1963	515.53	1.7941
1964	464.10	1.0607
1965	448.52	0.4143
1966	355.59	1.3943
1967	392.60	0.9889
1968	529.23	1.4436
1969	452.2	1.8703
1970	542.63	2.3818
1971	467.38	1.7754
1972	424.39	0.6328
1973	311.75	1.3853
1974	360.71	1.9121
1975	395.78	0.9955
1976	379.65	1.9774
1977	379.60	-0.0228
1978	417.99	1.3709
1979	410.73	-2.2023
1980	407.69	0.1862

Conti…

Year	Average ring width (μm)	Ring Width Index
1981	336.44	1.3279
1982	325.76	0.4152
1983	286.37	1.4382
1984	278.84	0.3067
1985	206.83	1.4250
1986	226.40	2.5345
1987	250.30	1.0805
1988	231.75	1.0127
1989	184.27	1.0498
1990	167.97	-1.3945
1991	285.61	1.7510
1992	178.83	2.1058
1993	209.20	-2.1410
1994	139.16	2.0560
1995	203.82	1.4982
1996	245.99	1.0065
1997	230.84	2.6747
1998	241.26	-0.8002

Conti…

Year	Average ring width (μm)	Ring Width Index
1999	147.29	1.4074
2000	151.45	-0.3183
2001	152.16	0.0806
2002	167.86	1.8989
2003	110.45	1.5442
2004	136.60	2.1364
2005	176.14	0.8629
2006	253.54	0.9340
2007	341.85	1.2248
2008	245.16	1.0975
Mean	**409.0302**	**1.079**

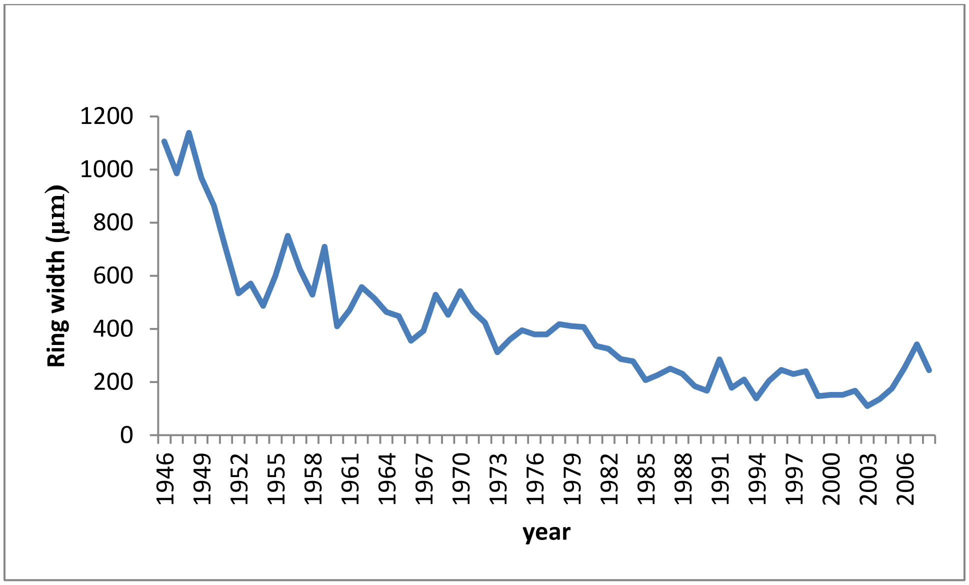


Figure 3. Average ring width of *Tectona grandis* at Vazhani

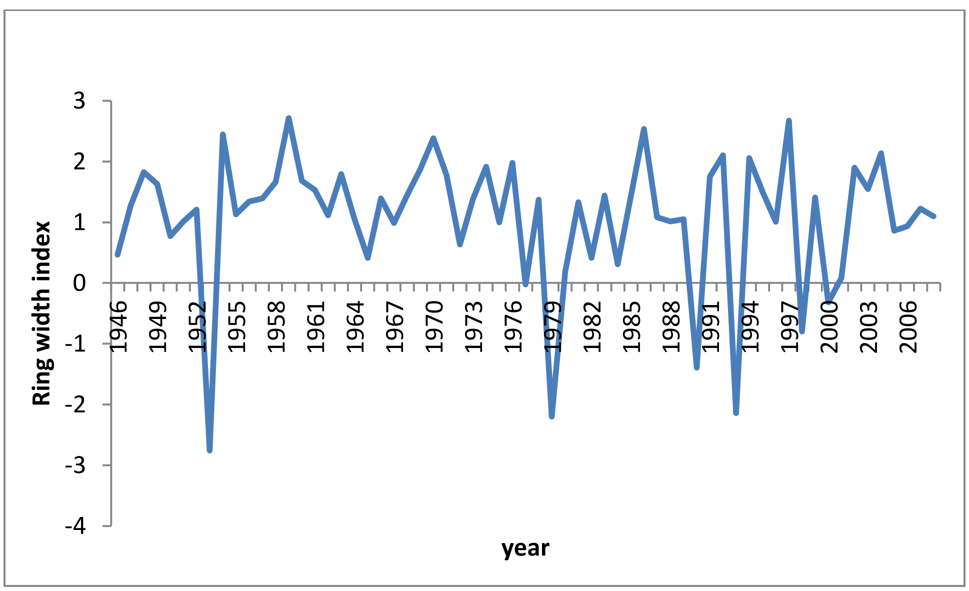


Figure 4. Ring Width Index of *Tectona grandis* at Vazhani

Table 3. Tree ring chronology statistics of *Tectona grandis* from the study sites

Chronology time span	1946-2008
Number of trees	10
Number of radii	36
Mean correlation among all radii	0.428
Signal to noise ratio	7.48
Expressed population signal	0.882

4.3. Ring Width Index chronology

From table 3 it was found that during the period 1946-2008, Signal to Noise Ratio and Expressed Population Signal recorded a value of 7.48 and 0.882 respectively.

4.4. Tree ring growth- climate relationship

4.4.1 Ring Width Index and temperature

Ring Width Index and annual temperature of Vazhani showed a significant positive correlation (r=0.299). Whereas temperature during South West monsoon showed a negative correlation (r=-0.311) (Table 4 and Figure 5).

4.4.2. Ring Width Index and rainfall

Average South West monsoon (r=0.226) showed significant positive correlation with Ring Width Index. Whereas average winter rainfall (r=-0.225) showed a negative correlation with a Ring Width Index (Table 5, Figure 6).

Ring Width Index had significant positive correlation with total rainfall of the previous year South West monsoon (r=0.317) and South West monsoon (r=0.300). Whereas total winter rainfall (r=-0.225) showed a negative correlation with Ring Width Index (Table 6, Figure 7).

4.4.3 Ring Width Index and Moisture Index

Correlation analysis between Ring Width Index and moisture index showed a significant positive correlation in previous year North East monsoon (r=0.517) (Table 8, Figure 8).

Table 4. Correlation between Ring Width Index and temperature

Index	Climate variable	Seasons						
		_JJAS	_ON	JJAS	ON	DJF	MAM	ANN
Ring width	Temperature	0.025	-0.156	-0.119	-0.091	-0.070	-0.311*	0.299*

*P<0.05

_JJAS: previous south west monsoon; _ON: previous north east monsoon; JJAS: south west monsoon; ON: North east monsoon; DJF: Winter; MAM: summer; ANN: Annual

Table 5. Correlation between Ring Width Index and average rainfall

Index	Climate variable	Seasons						
		_JJAS	_ON	JJAS	ON	DJF	MAM	ANN
Ring width	Rainfall (Average)	0.025	-0.138	0.226*	0.176	-0.225	0.162	0.179

*P<0.05

_JJAS: previous south west monsoon; _ON: previous north east monsoon; JJAS: south west monsoon; ON: North east monsoon; DJF: Winter; MAM: summer; ANN: Annual

Table 6. Correlation between Ring Width Index and total rainfall

Index	Climate variable	Seasons						
		_JJAS	_ON	JJAS	ON	DJF	MAM	ANN
Ring width	Rainfall (Total)	0.317*	-0.138	0.300*	-0.176	-0.225	0.162	0.179

*P<0.05

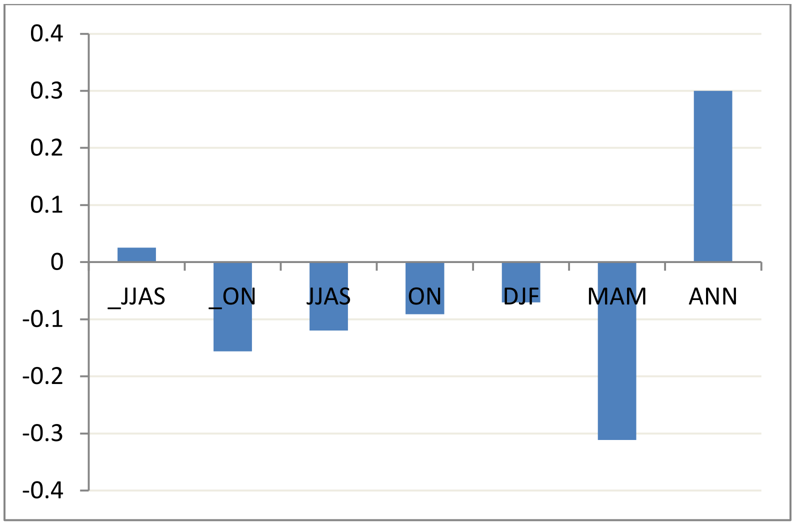
_JJAS: previous south west monsoon; _ON: previous north east monsoon; JJAS: south west monsoon; ON: North east monsoon; DJF: Winter; MAM: summer; ANN: Annual

Table 7. Correlation between Ring Width Index and Moisture Index

Index	Climate variable	Seasons						
		_JJAS	_ON	JJAS	ON	DJF	MAM	ANN
Ring width	Moisture index	-0.034	0.517*	-0.068	-0.116	-0.053	0.034	-0.114

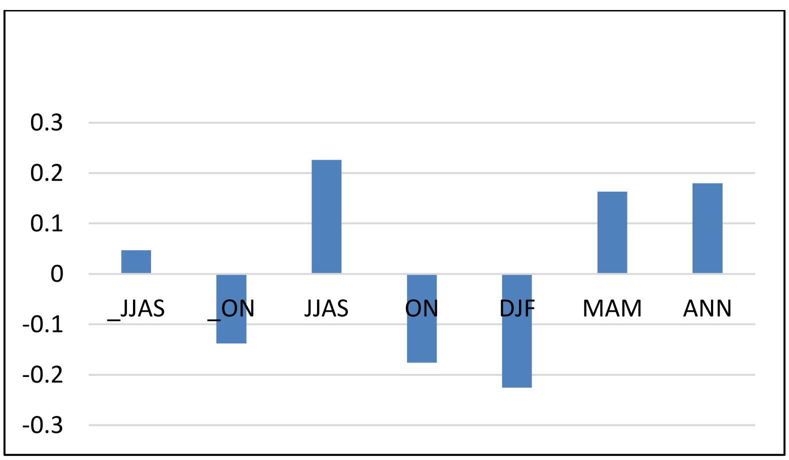
*P<0.05

_JJAS: previous south west monsoon; _ON: previous north east monsoon; JJAS: south west monsoon; ON: North east monsoon; DJF: Winter; MAM: summer; ANN: Annual



_JJAS: previous south west monsoon; _ON: previous north east monsoon;
JJAS: south west monsoon; ON: North east monsoon;
DJF: Winter; MAM: summer; ANN: Annual

Figure 5. Correlation between Ring Width Index and temperature

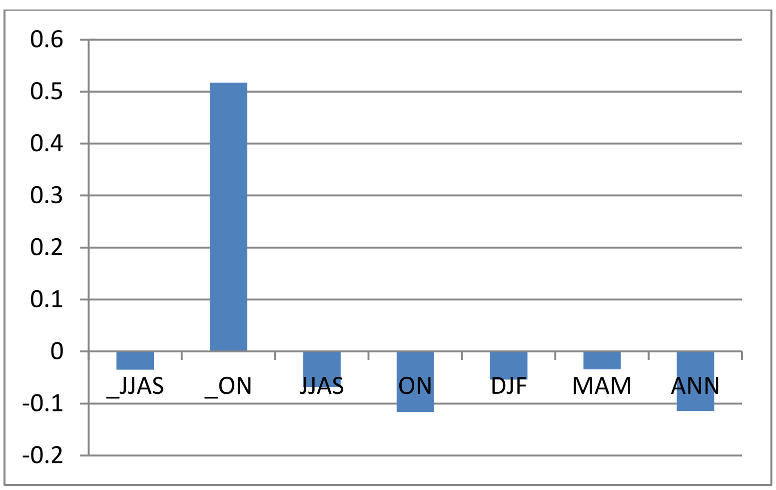


_JJAS: previous south west monsoon; _ON: previous north east monsoon;
JJAS: south west monsoon;ON: North east monsoon;
DJF: Winter; MAM: summer; ANN: Annual

Figure 6. Correlation between Ring Width Index and average rainfall

_JJAS: previous south west monsoon; _ON: previous north east monsoon;
JJAS: south west monsoon; ON: North east monsoon;
DJF: Winter; MAM: summer; ANN: Annual

Figure 7. Correlation between Ring Width Index and total rainfall



_JJAS: previous south west monsoon; _ON: previous north east monsoon;
JJAS: south west monsoon; ON: North east monsoon;
DJF: Winter; MAM: summer; ANN: Annual

Figure 8. Correlation between Ring Width Index and Moisture Index

DISCUSSION

CHAPTER 5

DISCUSSION

The results of the study entitled "Tree growth climate relationship in plantation teak (*Tectona grandis* L. f.) grown in Thrissur District, Kerala" is discussed in this chapter.

5.1. Ring Width

Ring width of teak at Vazhani site showed a decreasing trend. Highest ring width was recorded in the year 1948 (1138.28 µm) and the lowest in the year 2003 (110.45 µm). In the initial years of growth of a teak the ring width was found to be large and it gradually decreased with increase in age (Babu *et al.,* 2015). Similar results were also obtained by Sousa *et al.* (2012)who found that growth rings became large in the juvenile phase of teak and became smaller when it matures. Margret and Bernard, (2003) recorded average ring width of a 13 year old teak from two different sites of Puerto Rico as 5.33 mm and 5.59mm. A study conducted by Sinha *et al*. (2011)in 57 year old teak from Mundagod (Karnataka)and 130 year old teak from Chandrapur, (Maharastra) found that average raw ring width were 2.14 mm and 2.97 mm, respectively. A similar study by Deepak *et al*. (2010) also found that average ring widthof teak showed an age related growth trend. Therefore, site levels and age difference produced significant variation in tree ring width series (Brookhouse and Brack, 2008).Ring width of teak varied with age related factors compared to other tropical trees. Hence it is useful for dendroclimatological studies.

5.2. Ring Width Index chronology

Ring Width Index at Vazhani was found to be 1.079. Borgaonkar *et al*. (1996) reported that the Ring Width Index at Kufri was 1.00.

To estimate dendroclimatic potential, several statistics were being used such as Signal to Noise Ratio (SNR), and Expressed Population Signal (EPS). The indexes

Signal-to-noise ratios have been used to evaluate the relationship of strength of the common variance signal in tree-ring indices. SNR values are often used as a measure of index quality and it has no upper bounds. SNR greater than 1.0 indicates more common useful signal than the residual noise. The result showed that SNR of Vazhani is 7.48 (Table 3). This study indicated a good dendroclimatic potential for the study area of Vazhani of Thrissur District.

Ram *et al*. (2011) reported that a Signal to Noise Ratio of 8.1 was recorded for teak at Allapalli, Maharashtra. Similar results were reported by Ugulino *et al.* (2014) in central west region of Brazil. Deepak *et al.* (2010) also reported that Signal to Noise Ratio in Dandeli was 5.90 and for Shimoga were 2.69. Another study conducted by Babu *et al.* (2015) also reported similar result for Ring Width Chronology of teak in Vazhani, Thrissur district as 6.24.

The Expressed Population Signal (EPS) indicated usefulness of chronologies for climate reconstruction. EPS recorded at Vazhani was 0.882 (Table 3). In this study EPS value at Vazhani showed that it is suitable for dendroclimatic analysis.

Wigley *et al.* (1984) reported that an EPS greater than or equal to 0.85 can be accepted for dendroclimatic analysis and is not acceptable if it is below 0.85. Ugulino *et al*. (2014) found that the EPS value for Brazil was 0.880 and it was acceptable for determining dendroclimatic potential. A study conducted in Vazhani, Thrissur district had an acceptable value of EPS value of 1.307 (Babu *et al*., 2015).

5.3. Tree ring width and rainfall

Average rainfall during South west monsoon showed a significant positive correlation whereas average winter rainfall showed a negative correlation with Ring Width Index (Table 5, Figure 6). Ring Width Index has a significant positive correlation with total rainfall of the previous year South West monsoon and the total South West monsoon (Table 6, Figure 7).

D’Arrigo *et al.* (2006) reported tree ring studies of teak from central Java region showed that rainfall of the previous year’s South West monsoon has a significant positive relation to teak. They indicated that the moisture balance of the soil before the beginning of the next year growing season was important for teak growth. Sudheendrakumar *et al.* (1993) and Priya and Bhat (1999) studied about the relationship between rainfall and teak growth. They found that higher growth rates occurred during the months of higher rainfall. Accordingly Sinha *et al*. (2011) found that tree growth and rainfall from June to August of current year had a positive influence on the growth of teak. Previous year South West monsoon and rainfall during October played a major role in the growth of teak. A study conducted in four teak growing sites of Kerala *viz*., Pongnamkadu, Vazhani, Elanad and Karikadam, showed that ring width had significant correlation with the previous year South West monsoon (Babu *et al*., 2015).

In the case of winter precipitation it was negatively correlated with tree ring growth in *Pinus cembra* (Peterson and Peterson (2001). According to Fritts and Dean, (1992) North East monsoon had a negative correlation with Ring Width Index of teak grown in South America.

5.5. Ring width index and temperature

The correlation analysis between tree Ring Width Index and temperature from Vazhani showed a significant positive correlation with Annual temperature (Table 3, Figure 5). Besides temperature, other factors affecting the ring width are rainfall and Moisture Index.

Similar results were reported by Fritts (1976), in the northern boreal treeline where the tree growth was closely related to summer temperature. He also observed a temperature dependent growth rate at higher elevations. Cook (1987) and Juknys *et al*. (2002) suggested that the average monthly temperature is usually treated as the main factor that influenced tree ring formation. La Marche and Fritts (1971) and

Colenutt and Lukman (1996) also reported that annual increment growth of *Pinus cembra* was influenced mainly by summer temperature. Similar results was reported by Sinha *et al.* (2011), also found that temperature showed positive response with tree growth in the month of March due to summer.

Ma *et al.* (2014) observed that high temperature would enhance evaporation and affect the growth of trees China. He was also reported that the temperature strongly correlated with tree growth during the months from January to May. Singh *et al.* (2014) found that temperature had a positive relationship with growth of Himalayan pine in all months except in October and November.

The temperature in south west monsoon showed a negative correlation with Ring Width Index (Table 3, Figure 5). According to Ram *et al.* (2008) South West monsoon temperature hada negative correlation with Ring Width Index of teak from central India. They reported that higher temperature caused increased evaporation and evapotranspiration. It also limits photosynthesis and respiration during the subsequent growing season. Accordingly, the correlation between tree-ring index and temperature showed a significant negative relationship.

Shishkova and Panayotov (2013) reported that correlation with the average monthly temperature series was statistically significant and negative ($r > 0.273$) for the months from June to September of the year prior to growth. According to Babu *et al.* (2011) South West monsoon temperature showed a negative correlation with Ring Width Index of teak growing at Karikkadam, Thrissur district.

5.6. Ring Width Index and Moisture Index

The correlation analysis between Ring Width Index and moisture index showed a positive correlation during previous year North East monsoon (Table 5, Figure 7).

Ram *et al*. (2008) found that Moisture Index (MI) during monsoon season and annual scale indicate significant positive relationship from central India. Regional moisture index also show strong positive relationship with tree-ring index during previous year post-monsoon (−ON), which is statistically significant at 1% level. Soil moisture availability at the end of monsoon season plays a vital role in tree-growth processes.

SUMMARY AND CONCLUSION

CHAPTER 6

SUMMARY AND CONCLUSION

The present investigation "Tree growth climate relationship in plantation teak (*Tectona grandis* L. f.) grown in Thrissur District, Kerala" was carried out in the Department of Wood Science, College of Forestry, KAU, Vellanikkara, Thrissur during 2014-2015. The main findings of the study are summarized below.

The ring width of the samples collected from Vazhani showed a decreasing trend. Average raw ring width at Vazhani is (418.00 µm). Ring Width Index at Vazhani recorded a maximum value of 2.72 and a minimum of -2.76.

Correlation between Ring Width Index and temperature showed a significant positive correlation with annual temperature (r=0.299). A significant negative correlation was seen in South West monsoon (r=-0.311) but previous year South West monsoon did not show any correlation.

In the case of rainfall (average), significant positive correlation showed in South West monsoon (r=0.226). When Ring Width Index correlated with rainfall (Total), the previous year south west monsoon (r=0.317) and South West monsoon (r=0.300) showed a significant positive correlation but in case of winter rainfall (r=-0.225) it showed negative correlation.

Correlation between Ring Width Index and moisture index showed a significant positive correlation in previous year North East monsoon (r=0.517)

Hence the results of the present study showed that Ring Width Index had a significant relationship with the parameters like rainfall, temperature and moisture index.

The statistical parameters like SNR and EPS have good dendroclimatic potential at Vazhani. Signal to Noise Ratio (SNR) at Vazhani recorded a value of 7.48. Expressed Population Signal (EPS) recorded at Vazhani was 0.882.

REFERENCES

REFERENCES

Anchukaitis, K. J., D'Arrigo, R. D., Andreu, H. L., Frank, D., Verstege, A., Curtis, A., Buckley, B. M., Jacoby, G. C., and Cook, E. R. 2013. Tree-ring reconstructed summer temperatures from northwestern North America during the last nine centuries. *J. Clim.* 26: 3001–3012.

Andreu, L., Gutierrez, E., Macias, M., Ribas, M., Bosch, O., and Camarero, J. 2007. Climate increases regional tree-growth variability in Iberian pine forests. *Glob. Change Biol.* 13: 804–815.

Babu S., Anoop E. V., Anoob P., Vishnu R., Anish M., Adarsh M., and Kumar V. 2015. 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. *Res. J. Agriculture and Forestry Sci.*3(4).11-18.

Bhattacharyya, A., Yadav, R. R., Borgaonkar, H. P., and Pant, G. B. 1992. Growth-ring analysis of Indian Tropical trees, *Dendroclimatic potential*. 62: 736–741.

Bhattacharyya, A. and Yadav, R. R. 1999. Climatic reconstruction using tree-ring data from tropical and temperate regions of India – A review. *IAWA.* 20**:** 311–316.

Bhattacharya, A., Eckstein, D., Shah, S. K., and Chaudhary, V.2007. Analyses of climatic changes around Perambikulum, South India, based on early wood mean vessel area of teak. *Curr Sci.* 93(8): 1159-1164.

Bhattacharya, A. and Shah, S. K. 2009. Tree ring studies in India past appraisal, present and future prospects .*IAWA .J* .30 : 361-370.

Borchert, R. 1999. Climatic periodicity, phenology and cambium activity in tropical dry forest trees.*IAWA.J.* 2: 239-247.

Borgaonkar, H. P., Pant, G. B., and Rupa, K. K. 1994. Dendroclimatic reconstruction of summer precipitation of Srinagar, Kashmir. India since the late 18th Century. *Holocene.* 4: 299–306.

Borgaonkar, H. P., Pant, G. B., and Rupa, K. K. 1996.Ring-width variations in *Cedrusdeodara*and its climatic response over the western Himalaya.*Int. J. Climatol.* 16: 1409–1422.

Borgaonkar, H.P., Sikder, A.B., Ram, S., Kumar, R.K., and Pant, G.B. 2007. Dendroclimatological investigations of high altitude Himalayan conifers and tropical teak in India.*Korean J. Quaternary Res.* 21 (1): 15–25.

Borgaonkar, H. P., Sikder, A. B., Ram, S., and Pant, G. B.2010. El Niño and related monsoon drought signals in 523-year-long ring width records of teak (*Tectona grandis* L.F.) trees from south India, *Palaeogeogr. Palaeoclimatol.Palaeoecol.* 285: 74–84.

Briffa, K. R. 1984. Tree–climate relationships and dendrocli- matological reconstruction in the British Isles.Ph.D.Dissertation, University of East Anglia, Norwich, England, UK.

Briffa, K.R. and Jones, P.D. 1990. Basic chronology statistics and assessment. In: Cook, E.R., Kairiukstis, L.A. (Eds.), Methods of Dendrochronology: Applications in the Environmental Sciences. International Institute for Applied Systems Analysis, Kluwer Academic Publishers, Dordrecht, pp 137–152.

Briffa, K., Schweingruber, F., Jones, P., and Osborn, T. 1998b.Reduced sensitivity of recent tree growth to temperature at high northern latitudes.*Nature*.391: 678–682.

Briffa, K., Schweingruber, F., Jones, P., and Osborn, T. 1998a.Reduced sensitivity of recent tree growth to temperature at high northern latitudes.*Nature*.391: 678–682.

Briffa, K. R., Osborn, T. J., and Schweingruber, F. H. 2004. Large-scale temperature inferences from tree rings: a review. *Glob.Planetary Change*. 40: 11–26.

Brookhouse, M. Brack,C. 2008. The effect of age and sample position on eucalypt tree-ring width series. Can. J. For. Res., 38(5): 1144-1158.

Buckley, B.M., Cook, B.I., Bhattacharyya, A., Dukpa, D., and Chaudhary, V. 2005. Global surface temperature signals in pine ring-width chronologies from southern monsoon Asia. *Geophys.* 32: 2374-2375.

Buckley, B. M., Palakit, K., Duangsathaporn, K., Sanguantham, P., and Prasomsin, P. 2007. Decadal scale droughts over northwestern Thailand over the past 448 years: links to the tropical Pacific and Indian Ocean sectors. *Clim. Dyn.* 29: 63–71.

Buntgen, U., Frank, D. C., Schmidhalter, M., Neuwirth, B., Seifert, M., andEsper, J. 2006. Growth/climate response shift in a long subalpine spruce chronology. *Trees Structure and Function. 20:*99–110.

Chowdhury , K.A. 1964 . Growth rings in tropical trees and taxonomy *.J .indian Bot. soc* . 43: 334-342.

Colenutt, M. E. and Luckman, B.H. 1996.Dendroclimatic characteristics of alpine larch (*LarixlyaliiParl.*) at tree line sites in western Canada.*In* Tree Rings, Environment and Humanity.Proc.Int.Conference on Tree Rings, Tucson, AZ, 1994.Eds. J.S. Dean, M. Meko and T.W. Swetnam.Radiocarbon, Tucson.143–154.

Couralet, C., Sass-Klaassen, U., Sterck, F., Bekele, T., and Zuidema, P.A. 2005.Combining dendrochronology and matrix modelling in demographic studies: An evaluation for Juniperusprocera in Ethiopia.*For. Ecol. Manag.* 216: 317-330.

Cook, E. R. 1987. The decomposition of tree ring series for environmental studies, *Tree-Ring Bull.* 47: 37–59.

Cook, E. R., Seager, R., Cane, M., andStahle, D. 2007. North American drought: Reconstructions, causes, and consequences. *Earth-Sci. Rev.* 81: 93–134.

Cook, E. R., Anchukaitis, K. J., Buckley, B. M., D'Arrigo, R. D., Jacoby G. C., and Wright, W. E.2010. Asian Monsoon failure and megadrought during the last millennium.*Sci.*328: 486-489.

D'Arrigo, R. D., Jacoby, G. C. and Krusic, P. 1994. Progress in dendroclimatic studies in Indonesia.*J. Terrestrial, Atmos. and Ocean. Sci.* 5: 349–363.

D'Arrigo, R., Barbetti, M., Watanasak, M., Buckley, B.M., Krusic, P.J. Boonchirdchoo, S., and Sarutanon, S. 1997. Progress in dendroclimatic studies of Mountain pine in Northern Thailand.*IAWA J.* 18 (4): 433– 444.

D'Arrigo, R., Wilson, R, Palmer, J., Krusic, P., Curtis, A., Sakulich, J., Bijaksana, S., Zulaikah, S., and Ngkoimani, L.O. 2006.Monsoon drought over Java, Indonesia, during the past two centuries.*Geophy. Res. Lett.* 33: 470-546.

D'Arrigo, R., Wilson, R., Liepert, B., and Cherubini, P. 2008.Onthe 'Divergence Problem' in Northern forests: a review of the tree-ring evidence and possible causes. *Glob.Planetary Changes.* 60: 289–305.

D'Arrigo, R. D., Jacoby, G., Buckley, B., Sakulich, J., Frank, D. Wilson, R., Curtis, A., andAnchukaitis, K. 2009. Tree growth and inferred temperature variability at the North American Arctic treeline. *Glob.Planetary Change.* 65: 71–82.

D'Arrigo, R., Palmer, J., Ummenhofer, C. C.,Kyaw, N. N., and Krusis, P.2011. Three centuries of Myanmar monsoon climate variability inferred from teak tree rings. *Geophys.ResLett.* 38(1): 1-5.

Dave, Y. S. and Rao, K. S. 1982. Seasonal activity of the vascular cambium in GmelinaarboreaRoxb.*IAWA Bull.* 3: 59-65.

Deepak, M. S.; Singa, S. K.; Rao, R. V. 2009.Dendroclimatic potential of growth ring analysis in teak (*Tectona grandis*L.f.) from Western Ghats of Karnataka. *J. MyFor.* 45 (4):457-466.

Deepak, M. S., Sinha,S.K., and Rao, R.V.2010. Tree-ring analysis of teak (*Tectona grandis* L. f.) from WesternGhats of India as a tool to determine drought years.Emir. J. Food Agric. 22 (5): 388-397.

Dettinger, M. D., Cayan, D. R., Diaz, H. F., andMeko, D. M. 1998. North- South precipitation patterns in western North America on interannual-to-decadal time scales. *J. Clim.* 11: 3095-3111.

Die, A., Kitin, P., Kouame, F. N' G., Bulcke van den, J., Acker, J. V., and Beeckman, H. 2012. Fluctuations of cambial activity in relation to precipitation result in annual rings and intra-annual growth zones of xylem and phloem in teak (*Tectona grandis*) in Ivory Coast. *An. Bot. 110*: 861–873.

Detenne, P. 1989. Apperance and periodicity of growth rings in some tropical woods.*IAWA Bull.* 10: 123-132.

Eckstein, D., Odgen, J., Jacoby, G. C., and Ash, J. 1981. Age and growth rate determination in tropical trees: The application of dendrochronological methods. In: Bormann, F.H., Berlyn, G. (Eds.), Age and growth rate of tropical trees; new directions for research. Yale University, New Haven. pp. 83-106.

Esper, J., Schweingruber, F.H., andWiniger, M. 2002. 1300 years of climatic history for western Central Asia inferred from tree-rings. *Holocene.* 12: 267–277.

Fritts, H. 1976. Tree-Rings and Climate. Caldwell: The Blackburn Press.

Fritts, H. and Dean, J.S. 1992. Dendrochronoilogical modeling of the effects of climatic change on tree ring width chronologies from the chaco canyon area, South Western United States. Tree Ring bull. 52.

Gajewski, K. and Atkinson, D. 2003. Climatic change in northern Canada. J. *Environ. Rev.* 11: 69–102.

Gamble, J. S. 1902. A Manual of Indian Timbers, Dehradun.pp.457.

Guiot, J. 1991. The bootstrapped response function.*Tree- Ring Bull.*51: 39–41.

Harle, K., Etheridge, D., Whetton, P., Jones, R., Hennessy, K., Goodwin, I., Brooke, B., van Ommen, T., Barbetti, M., Barrows, T., Chappell, J., De Deckker, P., David, F., Gagan, M., Haberle, S., Heijnis, H., Henderson-Sellers, A., Hesse, P., Hope, G., Kershaw, P., Nicholls, N., 2005. Building a future on knowledge from the past: what palaeo-science can reveal about climate change and its potential impacts in Australia. CSIRO, Canberra.

Hughes, M. 2002. Dendrochronology in climatology—the state of the art.*Dendrochronologia.* 20, 95–116.

Jacoby G. (1989). Overview of tree-ring analysis in tropical regions. *IAWA Bull.* 10: 99–108.

Jacoby, G. C. and D'Arrigo, R. D. (1990).Teak (*Tectona grandis* L. F.), a tropical species of large-scale dendroclimatic potential.*Dendrochronologia*, 8: 83–98.

Jacoby, G. C. andArrigo, R. D. 1989. Reconstructed northern hemisphere annual temperature since 1671 based on high-latitude tree-ring data from North America. Clim. Change. 14(1): 39-59.

Jacoby, G. C. and Arrigo, R. D. 2006. Teak (*Tectona grandis* L. F.), a tropical species of large-scale dendroclimaticpotential.*Dendrochronologia*. 8: 83–98.

Jones, P. D., Lister, D. H., Osborn, T. J., Harpham, G., Salmon, M., and Morice, C. P. 2012, Hemispheric and large-scale land surface air temperature variations: An extensive revision and an update to 2010. *J. Geophys. Res. 117:127-139.*

Juknys, R., Stravinskiene, V., and Vencloviene, J. 2002.Tree-Ring Analysis for the Assessment of Anthropogenic Changes and Trends.*Environ.Monitoring Assess*. 77: 81–97.

LaMarche, V. C. and H. C. Fritts. 1971. Tree rings, glacial advance, and climate in the Alps. Z. *Gletscherk. Glazialgeol*.**7**:125–131.

Lamprecht H. 1986. Waldbau in den Tropen.Parey-Verl, Hamburg- Berlin, pp 287–290.

Leonelli, G., Pelfini, M., and Cherubini, P. 2008. Exploring the potential of tree-ring chronologies from the Trafoi Valley (Central Italian Alps) to reconstruct glacier mass balance.*Boreas.* 37 (1), 169–178.

Lilly, M.A. 1977. Environmental studies: An assessment of the dendrochronological potential of indigenous tree species in South Africa. Occasional paper no. 18, Department of Geography and Environmental Studies, University of the Witwatersrand, Johannesburg.

Ma, Y., Liu, Y., Song, H., Sun, J., Lei, Y., and Wang, Y. 2014.A Standardized Precipitation Evapotranspiration Index Reconstruction in the Taihe Mountains Using Tree-Ring Widths for the Last 283 Years.*Plos one*. 10(7): 133-137.

Managave, S. R., Sheshshayee, M. S., Borgaonkar H. P., and Ramesh, R. 2010. Intra-annual oxygen isotope variations in central Indian teak cellulose: Possibility of improved resolution for past monsoon reconstruction. *Curr. Sci.* 98: 930-937.

Mann, M. E., Bradley, R. S., and Hughes, M. K. 1999. Northern hemispheric temperature during the past millennium: inferences, uncertainties and limitations. *Geophys. Re- search Lett*. 26 (6): 759–762.

Margaret S. D. and Bernard R. P. 2003.A dendrochronological study of teak (*Tectona grandis*L. f., Verbenaceae) in Puerto Rico, Papers for oral presentation, International congress on quality timber products of teak from sustainable forest management: Kerala Forest Research Institute, Peechi, Kerala, India, 424- 433.

Murphy, J. O. and Whetton, P. H. 1989.A re-analysis of tree ring chronology from Java.*Proceedings of National Academy of Sci. Netherlands*. 92: 241–257.

Nobuchi T., Janmahasatien S., and Sakai, M. 1996. Seasonal changes of wood formation and some characteristics of heartwood formation in Teak (*Tectona grandis*) plantation.*Kasetsart J.(Natural Sci.).* 30: 254–263.

Palmer, W. C. 1965. Meteorological drought; *Research paper* 45 U.S. Dept. of Commerce.pp. 58.

Pant, G. B. and Borgaonkar, H. P. 1983. Growth rings of teak trees and regional climatology (An ecological study of Thane region); In: Environmental Management. Eds. Singh, L. R., Singh, S., Tiwari, R. C. and Srivastava, R. P. Geography Society. Allahabad, India. 153–158.

Pant, G. B. and Borgaonkar, H. P. 1984. Growth rate of Chir pine (*pinus roxburghii*) trees in Kumaun area in relation to regional climatology. *Himalayan Res. Dev*. 3 1–5.

Pandey, D. N. 2002. Global climate change and carbon management in multifunctional forests.*Curr. Sci.* 83: 593-602.

Peterson, D.W. and D.L. Peterson. 2001. Mountain hemlock growth responds to climatic variability at annual and decadal time scales. *Ecol.* 82:3330–3345.

Pisaric, M. F., St-Onge, S. M., and Kokelj, S. V. 2009. Tree-ring reconstruction of earlygrowing season precipitation from Yellowknife, Northwest Territories, Canada.*Arctic, Antarctic, and Alpine Res.* 41: 486–496.

Porter, T. J. and Pisaric, M. F. 2011. Temperature-growth divergence in white spruce forests of Old Crow Flats, Yukon Territory, and adjacent regions of northwestern North America. *Glob. Change Biol.* 17: 3418–3430.

Priya, P. B. andBhat, K. M.1998. False ring formation in teak (*Tectona grandis*L.f.) and the influence of environmental factors. *Forest Ecology Management, Amsterdam.*108: 215-222.

Priya, P. B. and Bhat, K. M. 1999. Influence of rainfall, irrigation and age on the growth periodicity and wood structure in teak (*Tectona grandis*). *IAWA J.* 20: 181–192.

Pumijumnong, N., Eckstein, D., and Sass, U. 1995. Tree-ring research on *Tectona grandis* in Northern Thailand.*IAWA J.* 16: 385–392.

Pumijumnong N, Eckstein D, Sass U (1995a) Tree-Ring research on *Tectona grandis* in Northern Thailand. *IAWA J.* 16(4): 385–392

Pumijumnong, N., Eckstein, D., Sass, U., and Park, W.K. 1999. Tree-ring network on teak (*Tectona grandis*L.) and its use for climatic reconstruction. In: “New Horizons in Wood Anatomy” (Kim YS ed). Chonnam National University Press, Kwangju, Korea, pp. 278-281.

Pumijumnong, N. and Wanyaphet, T. 2006. Seasonal cambial activity and tree-ring formation of *Pinus merkusii* and *Pinus kesiya* in northern Thailand in dependence on climate. *Forest Ecol. Manage*. 226: 279–289.

Pumijumnog, N.2012. Teak Tree Ring Widths: Ecology and Climatology Research in Northwest Thailand. *J. Sci. Technol. Dev*. 31(2): 165-174.

Ram, S., Borgaonkar, H. P., and Sikder, A. B.2008.Treering analysis of teak (*Tectona grandis*L.f.) in central India and its relationship with rainfall and moisture index.*J. Earth Syst. Sci.* 117(5): 637-645.

Ram, S., Borgaonkar, H. P., and Sikder, A. B. 2010. Varying strength of the relationship between tree-rings and summer month moisture index (April–September) over central India: A case study. *Quat. Int.* 212: 70–75.

Ram, S., Borgaonkar, H. P., and Sikder, A. B. 2011.Growth and climate relationship in teak trees from Conolly's plot, South India; *Curr. Sci.* 100(5): 630–633.

Ramesh, R., Battacharya, S. K., and Pant, G. B., 1989.Climatic significance of alfa D variations in a tropical tree species.Nature. 337:149-150.

Rao, Y. P. 1976. Southwest Monsoons. Meteorological monographs No. 1. India Meteorological Department, Pune.

Rao, K. S. and Dave, Y. S. 1981.Seasonal variations in the cambial anatomy of *Tectona grandis* (Verbenaceae).*Nord. J. Bot.* 1: 535–542.

Rao, K. S. and Rajput, K. S. 1999. Seasonal behavior of vascular cambium in teak (*Tectona grandis*L.f) growing in moist deciduous and dry deciduous forest of Gujarat. *IAWA J.* 20: 85–93.

Rodriguez , R, Mabres, A., Luckman, B., Evans,M., Masikas, M., and Ektvedt,T. M. 2005. "El Nino" events recorded in dry –forest species o the lowlands of north west Peru. *Dendrochronologia.*22(3):181-186.

Schongart, J. B., Orthmann, K. J., Hennenberg, S., and Porembski, W. S. 2006. Climate-growth relationships of tropical tree species in West Africa and their potential for climate reconstruction.*Glob. Change Biol.* 12: 1139-50.

Schweingruber, F. H. 1988. Tree Rings: Basics and Applications of Dendrochronology. Dordrecht: D. Reidel Publishing Company, 276 p.

Seo, J. W., Eckstein, D., Jalkanen, R., and Schmitt, U. 2011. Climatic control of intra-and inter-annual wood-formation dynamics of Scots pine in northern Finland.*Environ Exp. Bot.* 72: 422-431.

Shah, S. K., Bhattacharyya, A., and Chaudhary, V. 2007.Reconstruction of June–September precipitation based on tree-ring data of teak (*Tectona grandis* L.) from Hoshangabad, Madhya Pradesh, India.*Dendrochronologia.*25 :57–64.

Shishkova, V. and Panayotov, M. 2013. Climate-growth relationship of *Pinusnigra*tree-ring width chronology from the Rhodope Mountains, Bulgaria. *Bulg. J. Agric. Sci.* 2(19): 225–228.

Singh, J., Yadav, R. R., and Wilmking, M. 2009. A 694-year treering based rainfall reconstruction from Himachal Pradesh, India. *Clim. Dyn.* doi: 10:382-528.

Singh, J. and Yadav, R. R. 2014. Chir pine ring-width thermometry in western Himalaya, India. *Cur Sci*. 106: 5.

Sinha, S. K., Deepak, M. S., Rao, R. V., and Borgaonkar,H. P. 2011.Dendroclimatic analysis of teak (*Tectona grandis* L. f.) annual rings from two locations of peninsular India. *Curr. Sci.*, 100(1): 84-88.

Sousa, V. B., Cardoso, S., Quilho, T., and Pereira, H. 2012.Growth rate and ring width variability of teak, *Tectona grandis* in an unmanaged forest in East Timor.Rev.Biol.Trop. 60(1).483-493.

Speer, J. H. 2010. Fundementals of Tree-Ring Research.Tuscon, AZ: The University of Arizona Press.

Spurk, M. 1997. Dendroclimatological investigation on pine (pinussylvestris L.) growing at the planar-colline stage of Germany.*Dendrochronologia*. 15: 51-72.

Sudheendrakumar, V. V., Nair, K. S. S., and Chacko, K. C. 1993. Phenology and seasonal growth trend of teak at Nilambur (Kerala), India. *Ann. For. Sci.* (1): 42–46.

Szeicz, J. M. and MacDonald, G. M. 1995.dendroclimatic reconstruction of summer temperatures in NorthWestern Canada since a.d. 1638 based on age-dependent modeling. *Quaternary Res.* 44: 257–266.

Szeicz, J. M. and MacDonald, G. M. 1996.A 930-year ring-width chronology from moisture-sensitive white spruce (*PiceaglaucaMoench*) in NorthWestern Canada.*The Holocene* 6: 345–351.

Tardif, J., Camarero, J., Ribas, M., and Gutieˇırrez, E. 2003. Spatiotemporal variability in tree growth in the central Pyrenees: climatic and site influences. *Ecol. Monogr*. 73: 241–257.

Trouet, V., Coppin, P., and Beeckman, H. 2006: Annual growth ring patterns in Brachystegiaspiciformis reveal influence of precipitation on tree growth. *Biotropica.* 38: 375-82.

Ugulino, B., Latorraca, J.V.F., and Filho, M.T. 2014. Tree-ring growth response of teak (*Tectona grandis*L.f.) to climatic variables in central-west region of Brazil.*Sci.For.* 42(104): 473-482.

Wigley, T. M. L., Briffia, K. R., and Jones, P. D. 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology; *J. Clim. Appl. Meteorol*. 23: 201–213.

Wilmking, M., Juday, G., Barber, V., and Zald, H. 2004. Recent climate warming forces contrasting growth responses of white spruce at treeline in Alaska through temperature thresholds. *Glob. Biol.* 10: 1724–1736.

Worbes, M. 1995. How to measure growth dynamics in tropical trees.*IAWA J.Leiden* 16(4): 337-351.

Worbes, M. 1999. Annual growth rings, rainfall-dependent growth and long-term growth patterns of tropical trees from the Caparo Forest Reserve in Venezuela.*J. Ecol.* 87: 391-403.

Yadav, R. R. and Bhattacharyya, A. 1996.Biological inferences from the growth climate relationship in teak from India.*Proc. Indian Acad. Sci. 62* (3): 233–238.

Yadav, R. R. and Singh, J. 2002. Tree-ring based spring tempera- ture patterns over the past four centuries in Western Himalaya. *Quaternary Res.* 57: 299–305.

Zar, C. H., Teplyakov, V. K., and Naw M. L. T. 2014. Influence of climate factors on tree-ring growth in teak (*Tectona grandis* L. f.) plantations in the BagoYoma Range, Myanmar. *J.For. Sci. Technol.* 10 (1): 40-45

Zhu, H. F., Fang, X. Q., Shao, X. M., and Yin. Z. Y. 2009. Tree ring-based February–April temperature reconstruction for Changbai Mountain in Northeast China and its implication for East Asian winter monsoon. *Clim. Past.* 5: 661–666.

TREE GROWTH CLIMATE RELATIONSHIP IN PLANTATION TEAK (*Tectona grandis* L. f) GROWN IN THRISSUR DISTRICT, KERALA

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The present study “Tree growth climate relationship in plantation teak (*Tectona grandis* L. f.) grown in Thrissur District, Kerala” was conducted to develop tree-ring chronologies from plantation teak (*Tectona grandis*) at the site Vazhani in Thrissur forest division, Kerala, to understand the relationship between climate and tree growth. The work was carried out at the Department of Wood Science, College of forestry, KAU, Vellanikkara, Thrissur.

The study samples were selected from the sample collection in the Department of Wood Science, College of Forestry. The collected samples are thinned and sanded with different grades of sand papers to expose the growth rings. Statistical parameters like SNR (Signal to Noise Ratio) and EPS (Expressed Population Signal) showed a good dendroclimatic potential. Weather parameters such as rainfall, temperature and moisture index showed significant positive and negative correlation with Ring Width Index. Summer temperature, showed significant positive correlation and annual temperature showed negative correlation. South West monsoon rainfall showed significant positive correlation. Correlation between Ring Width Index and Moisture Index showed positive correlation during previous year North East monsoon.