Dendroclimatological investigations on teak (*Tectona grandis* L. f) from Nilambur, Kerala

By

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(2016-20-029)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled "**Dendroclimatological investigations on teak (*Tectona grandis* L. f) from Nilambur, 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 titles, of any other University or Society.

Vellanikkara
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CERTIFICATE

Certified that this thesis entitled "**Dendroclimatological investigations on teak (*Tectona grandis* L. f) from Nilambur, Kerala**" is a record of research work done independently by Ms Gouri S, 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 her.

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SYMBOLS AND ABBREVIATIONS

°C - Degree Celsius

IPCC - Intergovernmental Panel on climate Change

m - Meter

mm - Millimeter

SNR - Signal-to-Noise Ratio

EPS - Expressed Population Signal

ENSO - El Nino Southern Oscillation

PDO - Pacific Decadal Oscillation

NAO - North Atlantic Oscillation

cm - Centimeter

CDI - Cross Date Index

RWI - Ring Width Index

JJAS - Southwest monsoon (June, July, August, September)

-JJAS - Previous year southwest monsoon (June, July, August, September)

ON - Northeast monsoon (October, November)

-ON - Previous year northeast monsoon (October, November)

MAM - Summer (March, April, May)

FAO - Food and Agriculture Organisation

CO_2 - Carbon dioxide

IOD - Indian Ocean Diole

ISMR - Indian Summer Monsoon Rainfall

SOI - Southern Oscillation Index

SST - Sea Surface Temperature

INTRODUCTION

CHAPTER 1

INTRODUCTION

IPCC defines Climate change broadly as “any change in climate over time whether due to natural variability or as a result of human activity”. Trees are live, natural resources that are sensitive to climatic factors in their surroundings. Tree rings are an incredible accumulator of all types of meteorological data. Rain, temperature, cloudiness, humidity, and other meteorological variables make up our climate system, and tree rings are ideal for preserving this data.

Dendroclimatology is a branch of study that employs dendrochronology to recreate past climate conditions. Certain factors are required in dendroclimatology to reconstruct a climate, such as the presence of annual tree rings, limiting climatic factors, and long-lived trees. Multivariate analysis approaches based on yearly tree ring data have demonstrated that they may offer reliable information on the link between tree rings and climate (response function) as well as the nature of the climate itself and its variations over time (Fritts 1976). (Transfer functions).

Dendroclimatology may give a temporal perspective that focuses on environmental changes caused by climate change year to year. As a result, tree ring data can be utilised to recreate paleoclimates spanning decades to centuries (Fritts, 197I). The majority of other paleoclimatic data can only respond to century-long oscillations and cannot resolve annual variations. For a single climate record or several recordings, dendroclimatic reconstructions can be generated. Some of these numerous records can provide information on climatic changes based on geographic variances in tree chronologies (Fritts, 1976; Hughes et al., 1982; Stockton et al., 1985).

Many tree species, particularly in the tropics, have hazy rings or aren't tied to an annual growth cycle, or if they are, there aren't really any evident patterns that may be used to cross date them (Eckstein et al., 1981). On the other hand, tropical forest sites with cross-datingable ring species have provided useful chronologies (Villalba et al., 1985). The world's most important hardwood species is teak (*Tectona grandis* L.f).

The wood industry values it highly due to its remarkable mechanical and physical capabilities, as well as its inherent longevity and appealing aesthetic appearance (Kjaer et al. 1999). Tree ring width is one of the most important factors to consider while analysing tree development pace (Tian et al. 2009).

Teak is one of the few tropical species with visible growth rings. In connection to mensuration research; Brandis (1879) noted growth rings in various Indian tropical trees and documented yearly growth rings in teak.

The major aim of this work is to check the dendroclimatic potential of the plantation-grown teak from selected sites of Thrissur for the reconstruction of precipitation and temperature. This work deals with the following objectives;

i. To examine teak tree ring chronologies in Nilambur.
ii. Determine the link between tree growth and climate.
iii. Determine the dendroclimatic potential of ring width for temperature and precipitation reconstruction

CHAPTER 2

REVIEW OF LITERATURE

Paleoclimatology is the study of climate prior to the instrumental record (Bradley, 1985). Instrumental records are available for a period nearly 100-150 years, which is inadequate for explaining the climate variability and climate change in past millennial time scale. The climate change information in such time scale is often preserved in various natural archives (ice core, pollen, lake sediment, tree-ring etc.). These proxy records are of different temporal extent and resolutions. Dendroclimatic study was initiated by the insight of an astronomer, Andrew Ellicott Douglass. He was working at the Lowell Observatory in Flagstaff, Arizona, and was interested in the sunspot cycle and its relation to terrestrial climate. He envisioned tree ring as a proxy measure. He suggested that growth of trees is affected by the limiting factor. Dendroclimatic study extended in Europe by the end of the 1940s (Douglass 1914). In this thesis work, tropical Indian teak samples were studied. The natural distribution of teak extends from India to the Philippines. Bhattacharya and Yadav (1989) studies showed that teak is the best available tropical species for dendroclimatic study in India.

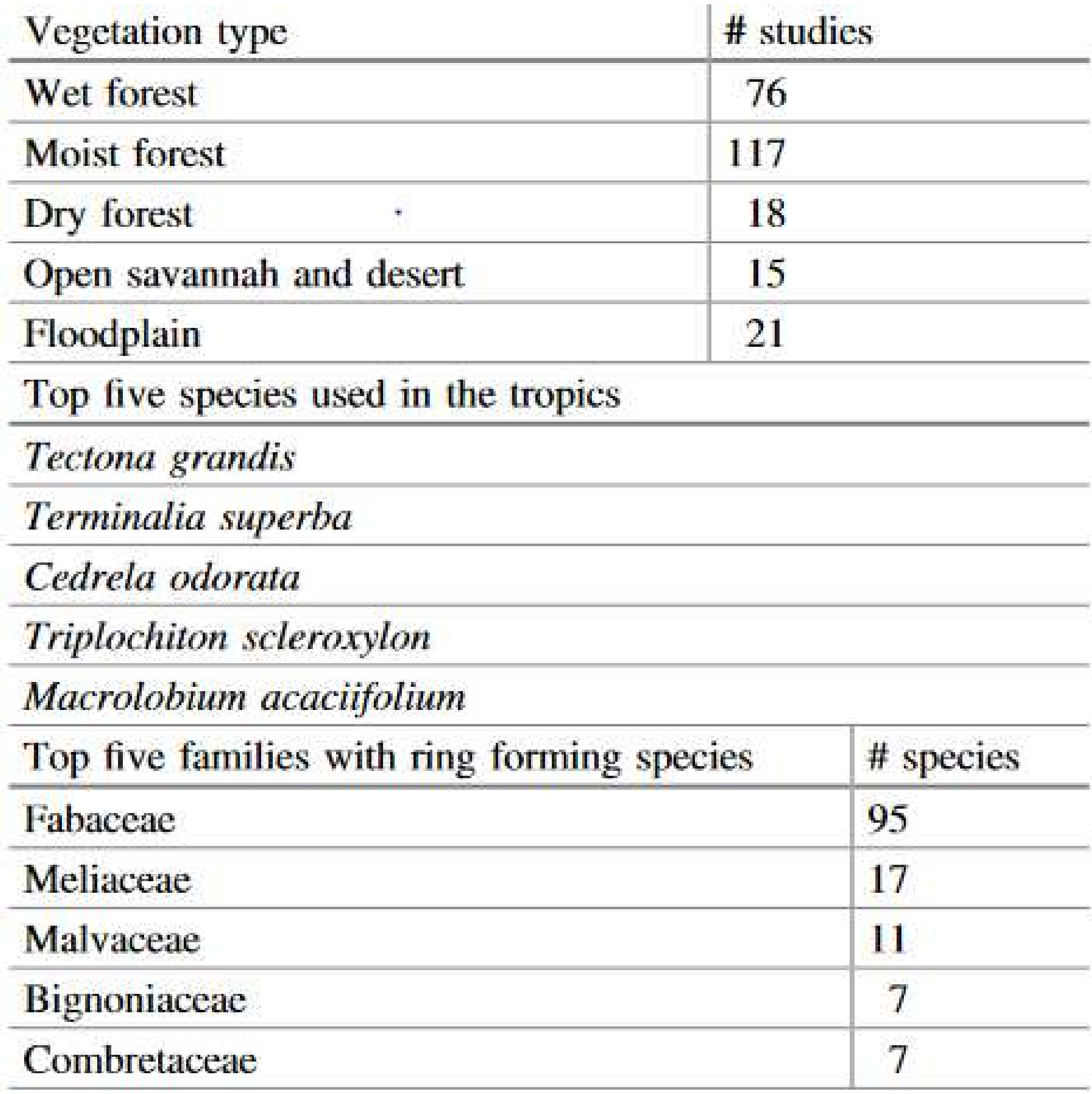
The wood industry values teak trees highly due to its remarkable mechanical and physical capabilities, as well as its inherent longevity and appealing aesthetic appearance (Kjaer et al. 1999). Tree ring width is one of the most important factors to consider while analysing tree development pace (Tian et al. 2009). It uses tree-ring measurements to rebuild yearly resolved, correctly dated proxy climate data for periods up to millennia and at spatial dimensions ranging from single sites to hemispheric sizes. These data contribute to and improve our understanding of the global climate system's behaviour by allowing for more precise sampling of natural climatic variability and trends, particularly over the last millennium and on decade/century timescales. The building of huge networks of tree-ring data sets and accompanying climate reconstructions has been one of the most important breakthroughs in dendroclimatology over the last 20 years. This has allowed large-scale modes of climate variability to be limited in time and space, allowing for a long-term view of the most important regional circulation patterns and a better understanding of how variability in these modes is related to forcing variables.

2.1 Dendroclimatological studies in tropical trees

Tropical trees are essential to the world's ecosystem. Tropical forests and woody savannas encompass 12–15% of the Earth's terrestrial area (FAO, 2006), are home to more than 40,000 tree species (Slik *et al.*2015), store nearly 60% of total global forest biomass (Pan et al.2011), and play a critical role in the earth's water, carbon, and nutrient cycles (Bonan2008; Spracklen *et al.*2012). It's vital to understand how tropical forests adapt to changing climate conditions because of their critical functions. This requires an understanding of tropical tree climate sensitivity and the long-term dynamics of tropical forests. Understanding the responses of tropical trees to changes in climate and CO2 is important for projecting the effects of future climate change (Zuidema *et al.*2013), while long-term data on tree ages and forest disturbance history is important for inferring carbon residence times in forests as well as the interactive effects of disturbance and climate change on forest dynamics (Zuidema *et al.*2013) (Babst *et al.*2014; Gebrekirstos *et al.*2014). Tree ring analysis can help researchers better understand how tropical forests respond to climate change (also known as dendrochronology). In temperate and boreal forests, tree rings have yielded significant insights into tree formation and function, as well as tree reactions to earlier climate change, but research in the tropics has lagged behind that in temperate and boreal forests (Fritts 1976; Speer 2010). While annual rings are less common in tropical trees than in temperate trees, annual rings have been observed in a large number of tropical species. In 1856, Brandis made one of the earliest reports of tree rings in a tropical tree species, finding that Teak (*Tectona grandis*) in Indonesia developed unique rings that he felt were formed in response to an annually repeating dry season. In 1881, Gamble confirmed this by counting rings on known-age plantation trees, and years later, Berlage reported the first tropical tree ring chronology on teak in 1931. The subject of tropical dendrochronology has advanced tremendously since then. Many tropical tree species in regions with seasonality in rainfall or flooding form distinct annual rings, according to two workshops specifically dedicated to this research field (1980 and 1989), which summarized the advances and concluded that many tropical tree species in regions with seasonality in rainfall or flooding form distinct annual rings (Bormann and Berlyn1981, Baas1989).

In 2002, Worbes looked at 139 species from terra firmes and Neotropical floodplains, and found growth bands in at least a third of them. The number of species with confirmed annual rings has increased substantially in the last decade as a result of increased study activities across the tropics (Zuidema *et al.*2012). Despite these advancements, the Berlage teak chronology (1514–1929) published in 1931 is still one of the world's longest tree ring chronologies. The lack of tropical chronologies in the International Tree Ring Database (Grissino-Mayer and Fritts1997) highlights undeniable difficulties in detecting tree rings for a large number of species, but it is also partially due to insignificant efforts and long-held doubts about ring development (Brienen et al., 2010).

Tree growth rings are crucial for understanding historical events such as fire, insect assault, climatic change, and so on (Sinha *et al.* 2010). Dendrochronology is the scientific study of this discipline. Trees in moderate climates have distinct growth rings. Due to a lack of seasonality and severe hibernation of cambial activity, which results in the absence of identifiable growth rings, tropical plants, unlike temperate trees, have been omitted from dendrochronology research. However, in connection to mensuration research, Brandis (1879) noted growth rings in numerous Indian tropical trees and documented yearly growth rings in teak. Gamble (1902) used yearly rings to study growth rings in a variety of tropical plants. Even in species where the rings were different, calculating their growth rings was thought to be inaccurate for determining the age (Coster. 1927). About a quarter of all tree species generate growth rings, according to estimates (Chowdhury 1939, 1940).



Vegetation type	# studies
Wet forest	76
Moist forest	117
Dry forest	18
Open savannah and desert	15
Floodplain	21
Top five species used in the tropics	
Tectona grandis	
Terminalia superba	
Cedrela odorata	
Triplochiton scleroxylon	
Macrolobium acaciifolium	
Top five families with ring forming species	# species
Fabaceae	95
Meliaceae	17
Malvaceae	11
Bignoniaceae	7
Combretaceae	7

Source: Ecological Insights from Tree Rings in the Tropics (Bhattacharya and Yadav (1989))

Table 1: A summary table of 130 studies shows the number of species having yearly rings by vegetation type, the top five species utilised in tree ring studies and the top five families with ring development in species.

2.2 Dendroclimatological studies in teak plantation

Teak (*Tectona grandis* Linn f.) is a commercially important trees that has been extensively researched for dendroclimatology, according to Sinha *et al.* (2019). Many climatic variables influence tree development, including sunlight, precipitation, temperature, wind velocity, and relative humidity. Other non-climatic variables, including inter-tree competition, insect pests, and soil nutrient qualities, may also have an impact on growth (Fritts, 1976). The width of tree rings is determined by several factors, including tree type, age, soil nutrient availability, and a variety of meteorological conditions Sinha *et al.* 2011). The year-to-year pattern of radial development in trees is primarily determined by the climatic conditions of various locations (Sinha *et al.* 2011). For dendroclimatic research, if tree development is limited directly or indirectly by some climate factors, that limitation may be calculated and dated. Dendroclimatology is the study of the development of growth rings in trees as a result of changes in climatic circumstances. The majority of this research is restricted to temperate areas of the globe. The monsoon climate regime affects a huge portion of India's tropical forests. It's estimated that around a quarter of all tropical tree species have growth rings (Sinha, 2012). Teak (*Tectona grandis* L. f) and toon (*Toona ciliata*) are appropriate for research demonstrating the datability of growth rings to precise years of development in tropical climates (Sinha, 2012). Teak, on the other hand, predominates in the research due to its widespread distribution and commercial significance. It has been studied using a dendroclimatological method at several Indian and international sites (Shah *et al.* 2007, Ram *et al*. 2008, Deepak *et al.* 2010, Sinha *et al*. 2011, Pumijumnong 2012, Kumar *et al.* 2014, Die *et al*. 2015. These teak dendroclimatological investigations were either conducted to extract historical climatic signals from tree rings, particularly monsoon rainfall and temperature, or to simply establish climate and tree development connections.

Source: Dendroclimatology in South East Asia, Pumijumnong (1995)

Figure: 1 (a) The teak tree in its native habitat; (b)-(e) Growth rings on several plates.

Pumijumnong et al. (1995) established a teak tree-ring study in northern Thailand, and found that the primary factor controlling the growth of teak is premonsoon rainfall (April to June). The reconstructed pre-monsoon rainfall shows an evidence of moderately wet environment in northern Thailand for the previous two decades.

Teak dendroclimatology research has been carried out in a few locations across India, including a moist deciduous forest in Thane, Maharashtra (Pant and Borgaonkas, 1983; Bhattacharya et al., 1992), a dry deciduous forest in Korzi, Andhra Pradesh (Yadav and Bhattacharya, 1996), and the Western Ghats (Buckley et al., 1989).

Teak tree rings might be useful proxy data for dendroclimatic research, particularly monsoon precipitation, according to these first investigations. The Western Ghats of India are also renowned as one among the greatest teak-growing regions across the globe.

2.3 Dendroclimatological studies in temperate regions from the year 2000

Due to the existence of distinctly differentiable seasons, which in turn generate distinct yearly rings in species present, most of which are gymnosperms, a significant amount of dendroclimatological study takes place in high latitudes, temperate, and subtropical parts of the world. Spurk studied the effects of precipitation, saturation deficit, relative humidity, and temperature on the development of *Pinus sylvestris* growing in 21 distinct locations across Germany (1997). Manrique and Cancio (2000) used a network of around 1000 tree ring samples to reconstruct the climate of Spain, mostly utilising *Pinus nigra*, *Pinus sylvestris, Pinus uncinata*, and Quercus spp. This dendroclimatic research yielded assessments of a sequence of climatic variables spanning almost a millennium. Brauning (2001) used a cluster of 15 Juniperus species chronologies in eastern Tibet to create a climatological history of the Tibetan plateau over the last thousands of years. High connection values were found in several chronologies for both rainfall variations over India and the Eurasian snow cover in winter, the latter being a critical factor in determining the intensity of monsoon circulation in the following summer. Wilson and Luckman used a novel set of Engelmann spruce (Piceaengelmannii) tree-ring chronologies at treeline locations in Interior British Columbia, Canada, to generate two separate models of maximal May-August temperatures (2003). Throughout their shared period, both models accurately predicted 53% of regional temperature changes and were tightly linked. The connections between summertime average, maximum, and minimum temperatures in this region have changed dramatically during the last several years. Akkemik (2003) examined *Cedrus libani* tree rings from three locations in Turkey, totaling 41 increment cores and three site chronologies. Low precipitation was a significant growth constraint. In an elevated, old-growth forest in Central Italy, Piovesan et al. (2003) created a long-term tree ring chronology for beech (*Fagus sylvatica*). For the period 1832-2000, pointer spacing and bootstrapped response functions were used to examine the climate signals of beech trees. The most important climate indications were precipitation in the middle of the summer (July-August) and the temperature in May.

Tree-ring samples of *Picea schrenkiana* were investigated along an altitudinal gradient in the centre of the Tianshan Mountains by Ting *et al* (2005). For three sites at various altitudes, ring-width chronologies were established. Precipitation was discovered to be the most important element restricting tree radial growth in the arid central Tianshan Mountain ranges, with precipitation in August of the previous growth year having a significant impact on tree radial growth across the entire altitudinal gradient, including at the cooler, higher altitude forest site.

Dendrochronology of Norway spruce (*Picea abies)* from two lowland Polish range centres was undertaken by Koprowski and Zielski in 2006. From May through July, spruce growth in northern Poland is strongly linked with rainfall. Tree-ring widths are more closely connected to March temperatures in southern locations. Zhao *et al.* discovered practical methods for generating tree-ring width chronologies in Larixgmelinii (larch) plantations in Northeast China (2007). According to the correlation analysis, the established chronology is more scientific and acceptable, and it may be used in the dendroclimatic study.

Climate change is responsible for around 40% of the variability in growth ring width, 30% by heredity, 20% by silviculture, and 10% by site circumstances and other factors, according to the findings. Vitas and Erlickyte (2008) investigated the impact of droughts on the radial development of Scots pine (*Pinus sylvestris*) in Lithuania, to determine the variations in drought impact on dry and wet growing sites. Using pointer years, the influence of droughts on pine radial development was studied. Negative pointer years have been blamed on winter colds and summer droughts. Droughts triggered six-pointer years of radial growth in pines throughout the twentieth century. Drought-affected pines in wet areas were found to be significantly more numerous than those in dry locations.

Cia and Liu (2013) presented the results of a dendroclimatological research of several coniferous species of trees: Larixprincipis-rupprechtii, *Picea meyeri,* and *Pinus tabulaeformis*, which grew along an altitudinal gradient in the Luliang Mountains in China. According to correlation analysis, the chronologies of bottom to intermediate sites were highly connected, and diverse species from the same site showed the strongest association. The uppermost site near the tree line did not respond to seasonal climatic factors in a significant way, whereas the four lower chronologies, regardless of tree species, were consistently and significantly influenced by both the mean temperature between May and July and precipitation data from March to June.

Galvin *et al.* (2014) successfully created a 31-tree, 204-year *Taxus baccata* chronology using *Taxus baccata* trees from the Killarney Nature Reserve in south western Ireland. The chronology demonstrated dendroclimatological potential, with climate responsiveness comparable to other important Irish tree species like Quercus. Muckross House synoptic station precipitation (1970-2007; r=0.521, p0.01) exhibited the strongest correlation with the chronology (1970-2007; r=0.521, p0.01). After 1970, temperatures from November to April exhibited a substantial connection with the chronology (r=0.605, p0.01 in Muckross House, r=0.567, p0.01 for Valentia Station).

2.4 Some dendroclimatic studies in the world

Tree-ring chronologies from the south western United States were used to reconstruct indices of precipitation, temperature, and other variables on a local (individual sites) to regional (small networks of sites, covering-synoptic-scale or larger) scale based on wood sampled from old-growth forests in the early twentieth century (Fritts,1976). Recent research in North America has employed even larger-scale tree-ring record networks to retrace past drought variations across millennia (eg: Cook et al., 2004; Cook et al., 2010).

Southern subtropical Asia's pine ring-width chronologies serve as global surface temperature indicators. Buckley, B. M., Cook, B. I., Bhattacharyya, Dupka, and V. Chaudhary compare Pinus ring width chronologies to global surface temperatures for the past 150 years in three locations across monsoon Asia (Bhutan, India, and Thailand) where the climate is dominated by the southwest monsoon in the boreal summer, shifting the correlations through three seasonal averages: two seasons preceding the monsoon and two seasons following the monsoon (jun-sep). The pine chronologies show patterns of relationship between SST and terrestrial temperature changes, implying that the equatorial seas influence moisture supply within those wet/dry tropical to subtropical regions. It also reveals pre-monsoon links between Asian land temperatures and those in the North Pacific. Such tropical-extra tropical climate linkages have been postulated by Deser et al. [2004] and D'Arrigo *et al.* [2005], which provide a research field.

Variation in Climate Signals in Teak Tree-Ring Chronologies in Two Different Growth Areas was investigated by Pumijumnong *et al.* (2018). They created two teak (*Tectona grandis* L.f.) tree-ring chronologies in Tak province, Northwestern Thailand, from Mae Tuen (462 years, 1555–2016) and Umphang (165 years, 1852–2016). Cross dating methods were used to check and verify the tree-ring width data and tree-ring chronology construction on 67 and 71 alive teak species, accordingly, and the ARSTAN programme was used to check and validate the tree-ring width information and tree-ring chronology building. In this work, teak tree-ring chronologies representing two distinct growth areas could never be cross-dated. As a result, the correlation between these chronologies is poor (r = 0.32, n = 165.0, p 0.010). This research demonstrates that owing to site diversity, non-climatic patterns such as terrain, nutrition, light, and internal variables can influence the formation of tree-ring structures from two regions. However, during the pre-monsoon season, these chronologies show a strong positive correlation with rainfall (April to May). The regional association patterns in these chronologies show that April to May rainfall was a major bottleneck for teak growth in northern Thailand. While rainfall has minimal influence on the Indian Ocean Dipole's (IOD) surface temperature difference, the IOD's unstable connection mostly with El Niño-Southern Oscillation (ENSO) has been observed. Tree-ring chronologies were connected with seasonal climatic variables to study the climatic signal in tree development. Teak chronologies showed a favourable relationship with precipitation and humidity levels throughout the same time period. Early monsoon rainfall was the major driver of teak development in this study location, according to the climate-growth link. Rainfall in Thailand during the intermediate monsoon months (March–July) may therefore be regarded as a significant factor influencing teak development.

There isn’t a lot of dendroclimatic research in Asia right now. Long climatic data and a large number of weather stations are necessary to understand the impact of climate conditions on South eastward Asian countries. These are the studies and our knowledge of Southeast Asia's climate constraints. More research on these topics should be encouraged. The lack of broad coverage of weather stations in Southeast Asia limits the availability of meteorological data. As proxies for previous climate data, lake sediments, colourful coral, pollen, archaeological or historical material, and plant or tree ring records were employed. Teak (*Tectona grandis* L.f.) is a Southeast Asian tree with yearly rings that are typically visible. It may be used to depict climate features as a good proxy.

Several organisations have attempted to build a high-resolution tree-ring data network spanning tropical South and Southeast Asia in the recent past in order to better understand monsoon variability and associated global variables (such as ENSO).

2.5 Some dendroclimatic studies in India

Bhattacharyya et al. conducted a Dendrochronological Reconnaissance of Northwest India's Conifers in 1988. Tree ring samples were collected across 6 coniferous varieties in the western Great Himalayas during the summer of 1984 to investigate if they might be used in dendroclimatic reconstruction. The Himalayan region has the most immediate potential for tree-ring study since it contains several conifers with close affinities to species from Europe and North America that are already recognised by western dendrochronologists. In sections of the Southwest's drier regions, drought-sensitive tree-ring series have been identified, and sub-humid plant groupings are similar. In 1980 and 1982, R. Ramash (then of Liverpool Polytechnic, now of the Laboratory of Tree-Ring Research) and M. K. Hughes (then of Liverpool Polytechnic, now of the Laboratory of Tree-Ring Research) conducted exploratory collections in the western Himalaya, with R. Ramash leading the way (Physical Research Laboratory, Ahmedabad, India). They collected comprehensive samples in 14 places across Uttar Pradesh and Himachal Pradesh, as well as in the Kashmir Valley's montane forests. Hughes and Davies (1987) established well-replicated site chronologies using densitometric features and ring widths of *Abies pindrow* and *Picea smithiana* from the Valley of Kashmir.

In central India, Sugam Aryal et al. looked at the relationship between rainfall and moisture index in teak (*Tectona grandis* L.F.) trees. The dendroclimatic capability of *Tectona grandis* ring width index chronologies from three locations in central India: Bori, Sajpur in Madhya Pradesh, and Edugurapalli in Andhra Pradesh, is assessed in this article. The tree-ring-width index is a measurement of a tree's width. The dendroclimatic potential of teak (*Tectona grandis* L.F.)

chronologies from three sites in central India was studied. The fact that the three site chronologies are so closely related suggests that the region's tree development is influenced by a single driving force. Rather than the direct impact of temperature on tree growth throughout the seasons, the main contribution of humidity indices and precipitation to tree development was identified through correlation study. Climate reconstructions based on conifer tree rings in the western Himalaya (Borgaonkar et al 1994, 1996; Pant et al 1998; Yadav et al 1999, 2004) revealed pre-monsoon and summer climatic variability in India during the past 300 years. Dendroclimatic research in the middle and mainland Indian regions, which itself is highly influenced by the monsoon climate system, is, however, underfunded. Several studies (D'Arrigo *et al.* 1994; Pumijumnong *et al.* 1995; Pant and Borgaonkar 1983; Bhattacharayya *et al.* 1992) have found that *Tectona grandis* has a high potential for reconstructed weather patterns (monsoon) related parameters (precipitation events, water stress frequency range and relative intensity, ENSO/El Nino).

Santosh *et al*. (2020) used ring width data from teak trees (*Tectona grandis*L.f) in Hoshangabad, Madhya Pradesh, India to reconstruct June–September precipitation. This research aims to investigate the dendroclimatological potential of teak (*Tectona grandis* L.f) for climate reconstruction in a new geographical location. The low monsoon precipitation has been shown to restrict the growth of this tree. Monsoon precipitation averages from the months of June through September have been recreated using teak ring-width data dating back to AD 1835. Several alternating eras of high and low monsoon occurrences may be seen in the reconstructed climatic data. Many of these dry monsoon years have been seen to correlate with India's most severe drought years. Tree-ring samples in the shape of discs were taken from the base of fallen teak trees in Madhya Pradesh's Hoshangabad Forest Division in March 1998. According to research on the tree-growth/climate connection, precipitation between June and September this year and October last year has a beneficial influence on teak development, but precipitation between January and May has a negative impact. Temperature has little effect on teak growth in this area. The relevance of rainfall from the southwest monsoon for teak development is demonstrated by the fact that there is a positive link between tree growth and climate from June to September. Rainfall from October of the previous season has a big impact. The present monsoon precipitation reconstruction from India's peninsular area is noteworthy because it adds to our understanding of the region's temporal variability by providing fresh data. This study confirms earlier findings on teak growth and climate, and highlights the use of ring width data from this tree in predicting monsoon rainfall in India's central area.

2.6 Dendroclimatic Studies in Kerala

Sinha et al. (2010) utilised tree ring research of Teak (*Tectona grandis* L.f.) from the Western Ghats of India to estimate drought years. This study reports on tree ring analyses of teak from two separate locations in the Western Ghats. Not only within a tree's radius, but also among trees growing in both locations, growth rings are cross-matched. Climate records and teak tree ring chronology revealed several alternating periods of low and high to extremely high rainfall years. The bulk of India's drought years correspond to the most common low rainfall years in two areas. By analysing the data, it was shown that teak's narrow growth rings correspond to years with little rainfall. As a result of the current study, it was discovered that *Tectona grandis* from the tropical area of India's Western Ghats offers a lot of promise for dendroclimatic analysis, especially for reconstructing previous rainfall changes.

El Niño and associated monsoon drought signals were studied in 523-year-long ring-width data of teak (*Tectona grandis* L.F.) trees across south India by Borgaonkar et al (2010). The study presents a 523-year (A.D. 1481–2003) Teak (*Tectona grandis* L.F.) tree-ring width index chronology from three forest locations in Kerala, Southern India. Dendroclimatological studies indicate a strong positive link between both the tree-ring index series and Indian summer monsoon rainfall (ISMR) and other environmental variables such as the Southern

Oscillation Index (SOI). Since the late 18th century, years of inadequate Indian monsoon rainfall (droughts) connected with El Niño have seen an increased frequency of poor tree growth. Many poor tree growth years have been seen in the past during recognised El Niño occurrences, which are thought to be connected to insufficient monsoon rainfall. The geographical connections between our Kerala tree-ring chronology and SSTs throughout El Niño areas follow similar patterns as ISMR. This connection suggests that the tree-ring records show substantial ENSO-related monsoon signals. These tree ring chronologies with high monsoon climate sensitivity are helpful tools for understanding the whims of monsoon rainfall prior to the collection of data.

Anish et al. (2015) studied short period chronology from the plantation teak of Thrissur, Kerala. The study showed that the tree ring parameters such as ring width and vessel area showed a significant positive relationship with prior year monsoon rainfall (South West and North East monsoon) and annual rainfall. In addition to this vessel area also showed a positive relationship with the previous year October-November temperature, current October-November temperature and annual temperature.

Babu *et al.* investigated the link between short-term chronologic characteristics (ring width, mean vessel area) and long-term chronologic characteristics-climate (rainfall, temperature) in teak plantations in Kerala's Thrissur district (2015). The preceding year's monsoons (southwest and northeast) and yearly rainfall were favourably associated with ring width index chronologies. They concluded that teak tree ring chronologies with short periods had high potential for dendroclimatic reconstruction in Kerala.

MATERIALS AND METHODOLOGY

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Introduction to methods of Dendroclimatology

In areas where growing season temperatures limit tree growth, tree rings can be used to reconstruct precipitation and temperature. Therefore in dendroclimatology, site selection is the crucial first step. Trees are chosen for sampling at a dendroclimatic site based on their apparent age and the absence of evidence of disturbance caused by non-climatic activity such as fire, wind, animals, earthquakes, volcanic eruptions, or people.

The second stage in dendrochronology is to ensure that a date is affixed to each tree ring from its year of origin. Cross dating is a technique for determining the age of a tree by comparing the configurations of fairly wide and narrow rings on several trees. While certain tree-ring collections cannot be cross-dated, cross-dating confidence can be high, if not irrefutable, when ring-growth variability patterns are stable and preserved synchronously over multiple trees. Tree rings are measured in dendroclimatology. Total ring width is the most common, workhorse variable in tree-ring research, with early wood and latewood widths frequently assessed independently. Wood density of rings may be assessed when necessary, with a focus on latewood maximum density, which is largely affected by temperature but can also be influenced by precipitation. The stable elements of carbon and oxygen have indeed been detected in tree rings to reconstruct climate. Frost damage, which implies freezing temperatures throughout the growing season, is another climatic characteristic worth noting in tree rings.

The cross-dating procedures, as well as the measured findings, are then checked. To detect mis fitting and/or outlier values, pre-whitening measurement series were used, followed by cross-correlating the residual series. The average correlation of individual trees to a master series consisting of all trees at a place is a quantitative diagnostic of cross-dating and signal strength of a collection. Tree-ring series are detrended once the date and measurement are verified. Ring-width series usually decline in a negative exponential fashion from pith to bark due to a geometric constraint of tree development, where plants contribute about the same amount of biomass each year to their ever larger self. Because it does not represent environmental influences, this tendency should be removed before conducting dendroclimatological research. When a series-length trend in tree rings, regardless of direction or precise mathematical form, cannot be consistently interpreted as an environmental signal, detrending occurs. The resultant standardised series are then merged into a single time series, i.e. the chronology, a crucial dendrochronological product, after detrending. The chronologies of the sites are well-replicated, with the majority having 20 or more trees. Most trees within site chronologies must have been impacted in the same manner by certain natural elements, which are usually climate, for them to display variability in common.

After data reduction, tree-ring chronologies are quantitatively related to climate. For this step, individual meteorological stations or several stations averaged over climatically homogeneous regions might be employed. Tree rings are typically linked with climate on a seasonal or yearly time scale, despite the fact that meteorological data is accessible in a number of time intervals, including hourly, daily, weekly, and monthly. The connection between tree rings and climate may be quantified using a variety of statistical approaches. Dendroclimatology's basic methodologies include correlation and response-function analysis, both of which have confidence intervals for determining significance. Models of dendroclimatic that incorporate several locations can be measured regionally.

After calibration, independent data not used in the calibration is used to confirm the relationship between tree rings and climate, such as split-period testing, prediction sum of squares, and/or comparison with climate reconstructed from other natural archive indicators of climate or qualitative climate indications found in historical documents. Once dendroclimate models have been confirmed, they are evaluated for the duration of their dendrochronology in order to reconstruct past climate. This phase presupposes uniformitarianism, the premise that underpins most natural-geological research, i.e., that the connection between tree growth and climate is the same now as it was previously. Although this assumption is periodically questioned, it is sufficiently true in dendroclimatology for climate reconstructions to be trusted. Because the biological foundations of tree development are unchanging, this is the case.

3.2 Study site and sample preparation

The main objective of this work is to build and analyse tree-ring chronologies of Nilambur plantation teak to determine the dendroclimatic potential of ring width and teak for temperature and precipitation reconstruction, as well as to examine the tree growth-climate connection. Random samples are taken from the site for this purpose.

The climate of the Nilambur forest division is influenced by the tropical monsoon. The summer season runs from March to May, with the southwest monsoon wet season following from June to September, and the northeast monsoon rainy season following from October to November. December to February is the winter season. Nilambur has substantial rainfall throughout the year, with a brief dry season. The average temperature in this area is 27.7 degrees Celsius. A total of 2666mm of precipitation falls per year.

Figure 2: Nilambur, the land of Teak

Figure: 3, Nilambur teak trees

Source: Nilambur Teak Plantation 0653

The world's oldest teak plantation is located 2 kilometres from Nilambur town in Malappuram district. It was founded in the 1840s and covers a massive 2.31 hectares. It was called for its designer, H.V. Conolly, the Malabar district collector at the time.

Teak tree samples (wood discs) from the teak plantation at Nilambur were gathered and kept in the laboratory for further observations.

The top part of the field-collected basal discs was levelled with a simple hand planer. The disc surfaces were then smoothed using sandpapers of grit grades 60, 80, 150, 220, 320, and 400 in selected 3 to 4 radii to reveal the growth rings for ring width measurement. To calculate the mean vessel area, chosen radii were further smoothened with grit sizes 600, 800, 1000, and 1500, in that order. After that, the samples were cleaned using a water jet to reveal the vessel lumen.

Figure 4: Smoothening of wooden discs surface using sandpaper

3.3 Measurement of ring width

Tree-ring measuring necessitates a high level of precision and consistency. LINTAB is a tree-ring analysis digital positioning table that can readily perform this operation. LINTAB is user-friendly, durable, and splash-proof. It is possible to measure stem discs as well as increment cores. LINTAB is a powerful tool for tree-ring analysis when used in conjunction with the TSAP program.

For tree ring studies, TSAP-Win is a sophisticated software platform. TSAP-Win covers the whole process, from measurement through evaluation of tree ring sequences. TSAP-Win offers a wide range of visual and statistical capabilities, as well as database connections.

Figure 5: Measurement of ring width using LINTAB

After smoothening, the growth rings on each disc were numbered and cross-matched on three to four radii. Using a digital camera coupled to a stereomicroscope (Motic), live pictures of the selected rings over the radius were seen on a computer screen, and ring widths were measured using the tree ring measurement platform LINTAB-6. Using TSAP Win software, the ring width of each and every year was calculated from the various radii was digitally recorded with 0.001 mm accuracy.

3.3.1 Features of TSAP Win software

Measurement and editing:

- Graphical data editing and control on screen
- Internal notebook: store your marks and text notes with the time series
- Support for LINTAB and other measuring devices (Aniol, Velmex, ...)

Graphical presentation:

- Graphs with single and multiple series
- Adjustable linear and logarithmic axis scaling
- Grid beams
- Core beams
- Optional display of header information in graphs

Data analysis:

- Graphical management of cross-dating (on-screen cross-dating)
- Simple chronology computation and analysis
- Indexation and standardisation methods
- Mathematical function library

Database:

- You pick the data to store with your series from a variety of header fields.
- TSAP chooses and organizes your data as needed.
- Easy data exchange: TSAP supports a variety of data formats (manual and automated / macros)
- Comfortable data editing (manual and automatic / macros) (e.g. Tucson, CATRAS).

3.4 Cross dating

Cross dating examines the structure of broad and thin rings in a tree to establish the location of actual ring borders based on biometric wood structure. This permits the real age of the specimen to be determined. Tree rings mimic a bar code in this sense, with varying line widths denoting each year. The patterns from one tree may be compared to those of other trees to see if all of the rings are represented in a sample. This method identifies where a sample's rings are missing or where a tree may have generated two or more rings in a single year. Cross dating yields precise dates for each ring in the tree-ring record. The selected radii were cross-dated using Stokes and Smiley's (1968) proposed techniques. The removal of fake rings and the insertion of missing rings were done to eliminate measuring inaccuracies.

3.4.1 Principle of cross dating

The core premise of dendrochronology is the notion of cross-dating. It is the primary instrument for determining the precise year of development of each yearly ring. A basic ring count without cross-dating is likely to create errors owing to locally missing or fake rings. When ring-width measurements are compared to yearly events like meteorological data, cross-dating is essential. Accurate calibration is difficult without perfect yearly tree ring dating since the chronology will be off by one or more years. For example, temperature data from 1973 might be matched incorrectly to yearly rings produced in 1972 or 1974, resulting in a deteriorated or non-existent climatic signal. In 1904, Douglass set forth the fundamentals of skeleton plotting.

Skeleton plotting: Using the skeleton plotting approach, every year of development is allocated to a vertical line drawn on a sheet of graph paper (usually graph paper with five lines per centimetre is used). The line's length indicates the ring's importance in the chronological signal. Narrow rings are more essential for capturing limiting environmental conditions, thus rings that are narrower than normal receive greater attention. As a result, the longer the line was drawn on the skeleton plan, the narrower the ring became. Because of the age-related growth pattern, as well as individual variability in tree development through time, the dendrochronologists utilizes a mental standardization procedure in which the relative width of the ring of interest is established by comparing it to three rings on each side utilises even rings to be compared, and the skeleton plot shows the narrowest rings. Lengthy trends or relatively brief suppressions are prevented from overwhelming the signal in chronology by this mental standardisation. The skeleton plot supports a range of line lengths from zero to ten, with zero representing an average or larger-than-average ring width and ten suggesting a missing ring discovered by cross-dating. To establish the overall scale of the skeleton plot, visually examine the sample to be dated to identify the smallest and biggest rings throughout the whole cross-sectional area. The smallest rings in the sample will have a length of nine boxes, and all samples should use the whole range from 1 to 9. The inter-annual ring-width fluctuation within the wood sample is depicted in standardisation plots, which show whether the wood is complacent with about equal ring widths or sensitive with a lot of variance in ring width. Many new dendrochronologists struggle with this seemingly random choice of the length of the line on the skeleton plot, but with experience, most researchers and students can generate skeleton plots that look quite similar. A computer program can replicate the process, demonstrating that it is not completely subjective (Cropper 1979). Dating, on the other hand, should always be done visually and maybe double-checked using various computational methods.

3.4.2 Cross dating by TSAP Win software

It employs a mix of visual (graphical) and statistical cross-dating techniques. Statistical models are useful for locating potential matches or verifying the dates of pre-dated time data.

3.4.3 Cross-dating parameters

To represent the quality of concordance between time series in dendrochronology, two primary concepts are used: Gleichlaeufigkeit and/or t-values. While the t-statistic is a commonly used test for correlation significance, Gleichlaeufigkeit was created as a unique tool for cross-dating tree-ring series (Eckstein and Bauch, 1969). Different sensitivity to tree ring patterns distinguishes these ideas. T-values are sensitive to extreme values, such as event years, whereas Gleichlaeufigkeit indicates the general agreement of two series. In the Cross-Date Index, a mixture of both is accomplished (CDI). Because the CDI is such a powerful parameter in cross-dating, the potential matches in the TSAP Win result are sorted by descending CDI.

3.5 Statistical analysis

3.5.1 Standardization

By applying an appropriate curve fit to the data set and computing a new time series, non-climatic signals such as biological and/or tree disturbances (exogenous) are eliminated from tree-ring data. ARSTAN software was used to de-trend and standardise the raw data for each tree (Cook et al., 1990). This was done in order to eliminate biological and geometrical patterns (age and size-related growth trends). To retain the elevated frequency response to climate changes, a cubic smoothing spline was employed with a 50% frequency response cut off of 2/3 mean series length (Cook and Peters, 1981). To eliminate the majority of the first-order autocorrelation, autoregressive modelling was applied to each de-trended ring-width record, and the pre-whitened sequence was then averaged using a bi-weight robust mean to obtain a chronology.

Construction of index values and chronology

Stokes and Smiley's techniques were used to cross-date the specified radii (1968).A ring width chronology was developed using the index values obtained.

$$\boxed{RI\ (t) = R\ (t)/Y\ (t)}$$

Where,

RI (t) -Ring width / Mean vessel area Index value for the year t
R (t) -Measured tree-ring datum for the year t
Y (t) - Expected yearly growth obtained from the smoothing spline

3.5.2 Correlation analysis

For the time period available, the link between climate and tree growth was investigated using high resolution, 0.5 0 x 0.5 0, grid climate data obtained from CRU TS V. 3.21 (Harris et al., 2014). Correlation analysis of tree ring data versus monthly, seasonal rainfall, and monthly, seasonal temperature using the statistical package PAST (Paleontological Statistics Version 4.06) was performed. For the analysis, a dendroclimatic year of 18 months from June of the previous year through December of the current year was used. The seven seasons defined were previous southwest monsoon (–JJAS), previous northeast 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 the number of trees/radii (N).

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

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

RESULTS

CHAPTER 4

RESULTS

This chapter presents the findings of the dendroclimatological study conducted on teak-growing plantations in Nilambur. It aids in understanding the tree development-climate link as well as the teak species' dendroclimatic potential.

4.1 Measurement of ring width

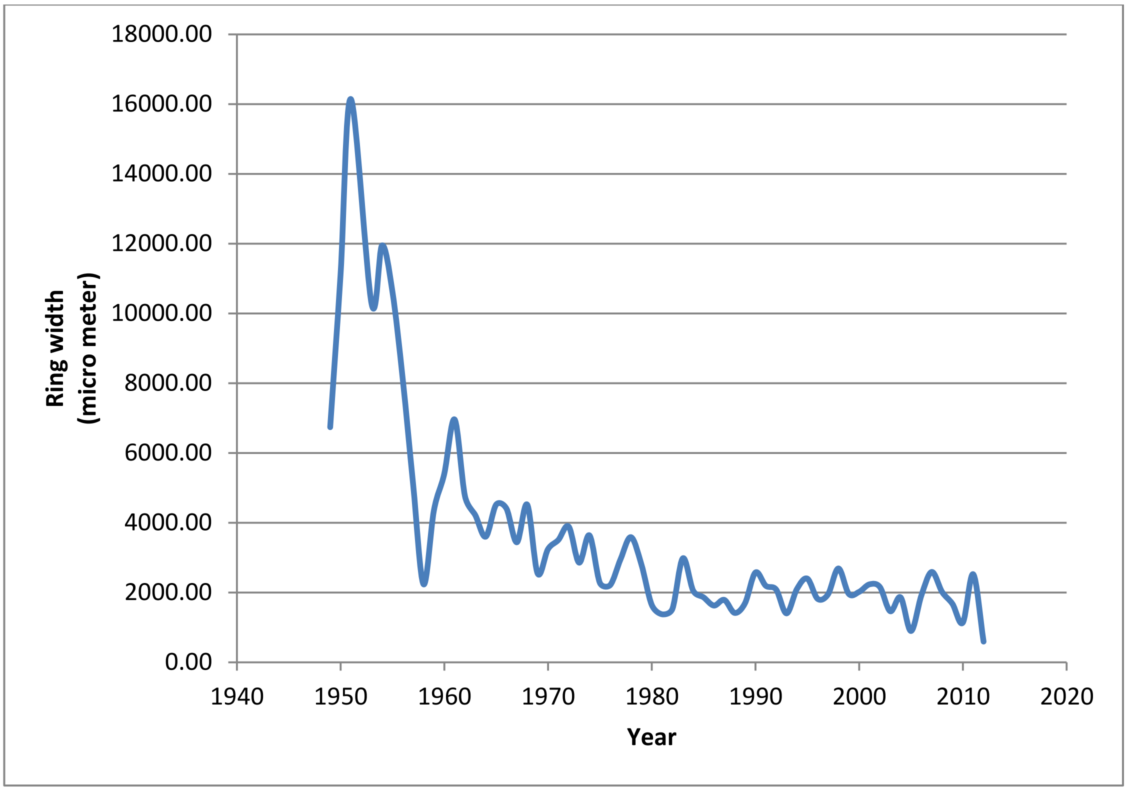
Nine radii in three discs from three trees were used for this investigation. Tree Ring Station with the help of TSAP Win software was used to measure the widths of the yearly growth rings in the samples. For this investigation, the chronological period studied was 1949–2012.

The average ring width measured was 3.555mm.

All of the random sites' ring widths showed an age-related increase tendency. The ring width was wide in the early years of growing, but as it grew older, the ring width shrank.

Average raw ring widths for each year from different random sites in Nilambur are shown in **figure 6.**

Figure 6: Average raw ring width of the samples from Nilambur



4.2 Cross dating

We noticed significant cross-matching between the samples and the reference sample during the software-aided cross-dating process. Only a few instances of false or duplicate rings have been reported. Most of the samples have a strong impact in the beginning. In the majority of the samples, false or duplicate rings are uncommon.

4.3 Standardization

The unit less quantity ring width index (RWI) has replaced tree ring width measurement, allowing for comparison with any chronology from any location and at any age group. All tree-ring chronologies perform well. High standard deviation and mean sensitivity scores clearly reflect the species' potential for dendroclimatic study.

4.4 Ring width index

We computed the Ring Width Index (RWI) for the chronology to better understand the samples' dendroclimatic potential. The mean correlations among all radii were calculated using this ring width index chronology and found to be 0.6159. For all samples, the ring width index was calculated by dividing the raw ring width value by the smoothed value.

Signal to Noise Ratio (SNR) and Expressed Population Signal (EPS) are two statistical variables that aid in determining the historical climate and dendroclimatic potential of samples. SNR denotes the signal intensity for each chronology era. SNR is defined as the ratio of the desired signal to an unwanted signal or noise. SNR values are frequently quoted as a measure of index quality and have no upper bounds. If the SNR value is > 1, it means that the desired signal is greater than the noise. In dendroclimatological studies, SNR values > 1 prove the samples' dendroclimatic potential to reconstruct past climates. The SNR value was 7.81 in this investigation, which is a high ratio for the index chronology.

The Expressed Population Signal (EPS) depicts the relationship between the samples' index chronology and the population from which they were collected. According to Wigely *et al.* (1984), if a chronology's EPS value is more than 0.85, it can be considered a credible chronology for dendroclimatic reconstruction. The timeline will be rejected if the EPS value is less than 0.85. In this investigation, the EPS values for the timeline were found to be greater than 0.85, that is, 0.896. As a result, the current index chronologies offer a useful tool for dendroclimatic reconstruction of historical climate for the particular region.

Figure 7: Ring width index chronologies from Nilambur

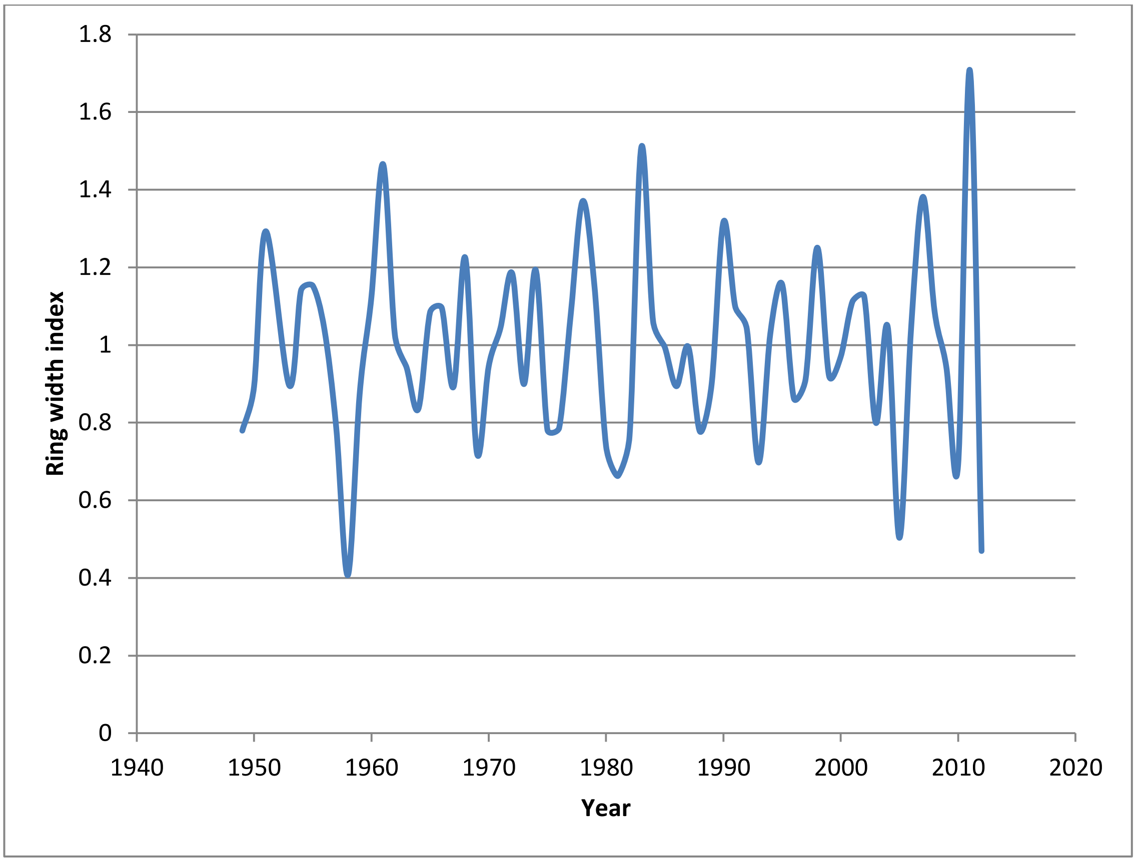


Table 3: Statistical data of Tree ring Chronology of *Tectona grandis* from the research Area

Chronology time span	1949-2012
Number of trees	3
Number of radii	9
Mean correlation among all radii	0.6159
SNR	7.81
EPS	0.896

4.5 Correlation between climate and ring width

4.5.1 Monthly precipitation and ring width

The chronologies from random sites of Nilambur showed a positive correlation with (0.23) June, (0.354) July, (0.385) August, and (0.355) October precipitation of the previous year. However, the chronology revealed a negative correlation (0.482) with the prior year's December precipitation. The current year's (1949-2012) precipitation (0.313) May, (0.324) July, and (0.383) December had a positive correlation with the chronology.

4.5.2 Temperature and ring width on a monthly basis

In the case of temperature, the chronologies showed a negative correlation with (0.307) June and (0.361) December temperatures of the previous year, except with July (0.318) temperatures, which showed a positive correlation. The chronology showed a positive correlation with the (0.332) November temperature of the current year and a negative correlation with the temperatures of March (0.356), April (0.291), and July (0.349) in the current year.

4.5.3 Seasonal climate and the width of the ring

In Nilambur, the previous year's southwest monsoon (pJJAS) had a positive influence on the (0.392) ring-width chronologies and the October-November previous year's precipitation also had a positive correlation (0.272). The current year's October-November precipitation had a positive influence (0.354).

In the case of seasonal temperature, the previous southwest monsoon (pJJAS) temperature (0.251), the previous October-November temperature (0.29), and the March-to-May temperature (0.382) had a negative influence on ring-width chronologies. The current year temperature during the southwest monsoon (JJAS) had a positive influence (0.351). Other seasonal temperatures during October-November (0.279) also showed a positive influence.

Figure 8: correlation between precipitation and ring width chronology

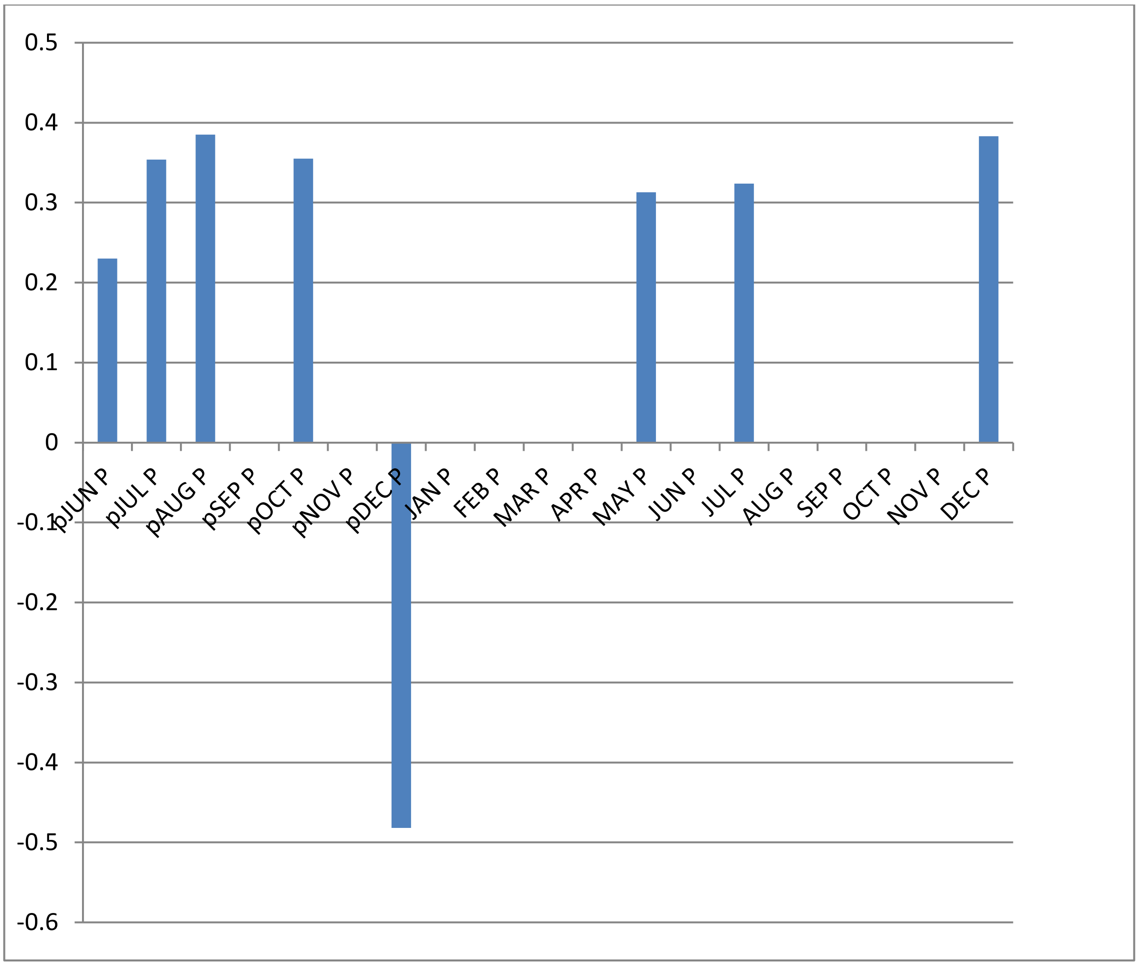
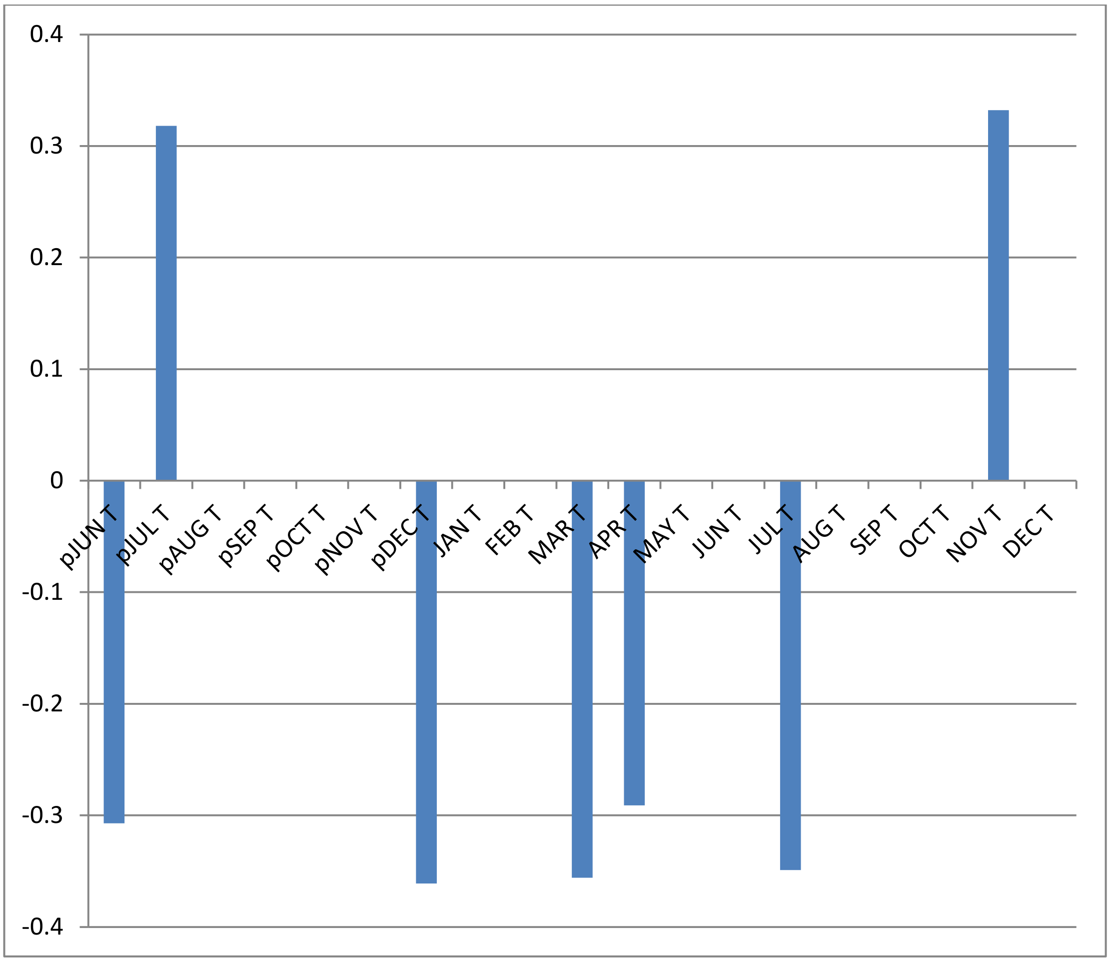


Figure 9: Correlation between temperature and ring width chronology



DISCUSSION

CHAPTER 5

DISCUSSION

This study looked into the dendroclimatic potential of teak from selected planting areas in Kerala's Nilambur region. The conclusions of the study, as well as findings from other related studies, are presented below.

5.1 Ring width

When it came to ring width, there was an age-related upward trend. That means the average tree ring width of the samples was large throughout their first year of development. The ring's width was steadily reduced during the next year. In their final year of development, they also had a low ring width value. This implies that as the tree becomes older, the ring width of the teak decreases. According to Brookhouse and Brack (2008), tree ring width variance was impacted by site characteristics as well as age differences. The locations in Karnataka and Maharashtra have little rainfall compared to Kerala, whereas the ones in Puerto Rican have substantial rainfall (Purkayastha and Satyamurthi, 1975). They claimed that the site factor influenced teak growth by 3.14 percent.

The average ring width of all the samples obtained from the present study was 3.555 mm.

Deepak *et al*. (2010) cited 57-year-old teak from Dandeli (2.15 mm) and 59-year-old teak from Shimoga as examples of typical raw ring width from other locations in Peninsular India (3.10 mm). Sinha *et al*. (2011) found that the average raw ring widths of 57-year-old teak from Mundagod (Karnataka) and 130-year-old teak from Chandrapur (Maharashtra) were 2.14 mm and 2.97 mm, respectively. The average ring widths from these studies were approximately similar to that from the present study.

Verheyden *et al.,* (2004) used polished discs to establish the presence of early wood (dark) and latewood (light) rings in *Rhizopora mucronata*, a growth ring-less species. These rings might be used to calculate the tree's age and growth rate.

5.2 Tree ring chronology

5.2.1 Ring width index chronology:

Ring width index chronologies from the study site were analysed to obtain the dendroclimatic potential of teak. By analysing the Ring width index chronology, the mean correlation among all radii was found to be high at 0.6159.

Two statistics are utilised to evaluate the dendroclimatic potential of the sample's index chronology: signal to noise ratio (SNR) and expressed population signal (EPS). SNR has been utilized to evaluate strength of the common variance signal in the indices, according to Cook and Kairiukstis (1990). There should be more than one SNR to consider whether the chronology is suitable for dendroclimatic reconstruction. The SNR value for the index chronology of the samples under investigation was high at 7.81, indicating that the samples had a strong dendroclimatic potential for past climate reconstruction.

The EPS is used to assess the relationship between the index chronology and the population from which the samples were collected. According to Wigely *et al.* (1984), the chronology is appropriate for dendroclimatic reconstruction if the EPS value is equal to or greater than 0.85. The EPS value for this investigation was 0.896, indicating that the samples were suitable for dendroclimatic reconstruction.

5.3 Correlation between climate and ring width

Rainfall had a positive influence on the tree growth in the study site in all seasons. The great influence of precipitation on tree growth in wet and cold Mediterranean climates except in winter was revealed by Berger *et al.* (1979). The temperature in the study site had a negative influence on the trees' growth. In the pre-monsoon season, according to Borgaonkar *et al.,* (1996), the temperature progressively rises beyond the average yearly value, with May being the warmest month. But there is a very small precipitation amount during the pre-monsoon months. The pre-monsoon season coincides with the early growth period of trees. So the extreme heating decreases the moisture level, but more precipitation increases the growth of the tree.

In the studies of Corlett, (2016), Vlam *et al.*, (2014), Bonal *et al.*, (2016), Pumijimnong & Buajan, (2013) revealed that in tropical regions, less precipitation and warmer temperatures cause extreme drought conditions which decrease tree growth. This indicates the radial growth of teak is influenced by precipitation and temperature during the dry season. The present study also observed a negative correlation of temperature on tree growth during the dry season (MAM).

CONCLUSION

CHAPTER 6

CONCLUSION

Several important observations obtained from the different stages of this study are presented in this section. These conclusions may help to get into more studies about this subject.

Teak (*Tectona grandis*) is a tropical tree with a high dendroclimatic potential for historical climate reconstruction. Tree rings give long-term meteorological data that may be used to determine previous climatic conditions dating back hundreds of years. The signal-to-noise ratio of teak samples obtained from Nilambur teak plantations was high, indicating that the species present here have a high dendroclimatic potential to reconstruct temperature and rainfall. This knowledge might assist farmers in developing a plantation management strategy. We can learn about the timber quality of the trees in these plantations by analysing historical climatic circumstances that influenced the teak plantation.

The current analysis indicated the site's strong dendroclimatic potential, as well as the necessary levels of signal-to-noise ratio and expressed population signal value. The tree-ring width, which was used as a growth metric for this study, was impacted by the site's temperature and rainfall.

In Nilambur, the previous year's southwest monsoon (pJJAS) had a positive influence on the ring-width chronologies and the October-November previous year's precipitation also had a positive correlation. The current year's October-November precipitation had a positive influence. In the case of seasonal temperature, the previous southwest monsoon (pJJAS) temperature, the previous October-November temperature, and the March-to-May temperature had a negative influence on ring-width chronologies. The current year's temperature during the southwest monsoon (JJAS) had a positive influence. Other seasonal temperatures during October-November also showed a positive influence.

Many additional chronologies from diverse sites may aid us in making climate and tree growth projections by providing a broad grasp of previous monsoon variability.

SUMMARY

CHAPTER 7

SUMMARY

A dendroclimatic investigation on teak (*Tectona grandis*) from Nilambur, Kerala was done for 3 trees from 1949 to 2012 from the randomly selected sites in Nilambur, Kerala. The investigation was conducted in the Department of Forest products and utilization, College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur.

7.1 Tree-ring data: Tree ring samples of teak (T. *grandis*) from Nilambur, Kerala which were collected by College of Forestry, Kerala Agriculture University, Thrissur have been used in the analysis. With this set of raw material, I did all dendrochronological analysis in the laboratory, including Sanding of wooden disks for the measurement of samples, ring width measurement, cross dating . This was an important aspect of my project program to learn the basic dendrochronological techniques. TSap-win software along with LINTAB-6 is used for the completion of these steps.

7.2 Chronology development: The aggregate effect of many internal and environmental signals including climatic and non-climatic factors like biological aging, local endogenous disturbances due to competition among the trees and exogenous disturbances caused by fire, pests, disease, pollution etc. can be seen in these ring width series. That is, it indicates the resultant annual growth patterns of the trees with the effect of these climatic and non-climatic signals. Appropriate detrending method (standardization) cubic spline smoothing, has been applied to the individual ring width series to minimize non-climatic signals. The ring width series, thus filtered out, are called the index series and contain large variance due to climatic influences which resulted in the development of site chronologies which is used for further studies to evaluate their dendroclimatic potentiality.

7.3 Tree growth-climate relationships: One of the main purposes of the study was to find out reliable relationship between tree-ring variations and climatic parameters like monthly temperature and rainfall which are statistically significant, for the reconstruction of these parameters over the earlier period to the instrumental record. The standardized index series contain large climate signal compared to those of raw ring-width series. These index chronologies are correlated with regional climatic parameters to study the association between tree growth and climate.

7.4 Dendroclimatic potential: The chronologies suitable to use in climatic reconstruction were expected to have high Signal to Noise Ratio (SNR) and Expressed Population Signal (EPS) >0.85 (Fritts, 1976).

The results are summarised below:

1. The average raw ring width obtained from the measured ring width value using TSAP Win software was 3.555 mm.
2. The nine radii from 3 basal discs were analysed. The mean correlation among all radii of the ring width index chronology was 0.6159.
3. The signal-to-noise ratio (SNR) value was high for the index chronology (7.81), revealing the high dendroclimatic potential for the sites for the past climatic reconstruction.
4. The value of the expressed population signal (EPS) was also moderately high for the index chronology, revealing the reliability of the population for further dendroclimatic analysis.
5. Rainfall always had a positive influence on tree growth during the southwest and northeast monsoons of the previous and current years.
6. The temperature had a negative influence on the tree during the previous southwest monsoon (pJJAS) (0.251), the previous October-November temperature (0.29), and the March-May temperature (0.382). The current year temperature during the southwest monsoon (JJAS) had a positive influence (0.351). Seasonal temperatures during October-November (0.279) also showed a positive influence.

CHAPTER 8

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Dendroclimatological investigations on teak (*Tectona grandis* L. f) from Nilambur, Kerala

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THESIS

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ABSTRACT

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Dendroclimatology is the branch of dendrochronology for the reconstruction of past climate by using tree-rings as a proxy. Paleoclimatology is the study of climate prior to the instrumental record. Measurement records on weather parameters are inadequate for explaining the climate variability and climate change in past millennial time scale. Paleoclimatic data helps in testing the hypothesis about the causes of climate change. When the past climatic fluctuations are understood, the climatic variations in the future could possibly be predicted. Tree ring chronologies can extend more than 1000 years in some cases, with some high-altitude species like *Pinus longaeva* Bailey and *P. jiexilis* James, giving long records of the yearly climate.

The goal of this study was to look at teak tree ring chronologies in Nilambur, identify the relationship between tree growth and climate, and ultimately assess the dendroclimatic potential of ring width for temperature and precipitation reconstruction. Cross-sectional discs of three trees in a time span of 1949 to 2012 collected from random locations in Nilambur by the College of Forestry, KAU, Thrissur were utilized. TSAP-Win software in association with LINTAB was used to measure and cross date the average ring width. The programme ARSTAN was used to standardize the tree ring data using a tool called cubic smoothing spline to remove the non-climatic signals of the series which result in tree ring chronology.

Climate data was obtained from CRU TS V.3.21 (high resolution grided climate data set) and by using PAST software, a bootstrap correlation with moving intervals (correlating RWI value with climate data) was done to determine the relationship between tree growth and climate. Monthly seasonal rainfall and monthly seasonal temperature were used as the climatic parameters for the study. Rainfall showed a positive correlation with tree growth and temperature a negative correlation with tree growth. All chronologies exhibited desired levels of statistical metrics such as Signal to Noise Ratio (SNR) and Expressed Population Signals (EPS) which are the statistical parameters to determine the dendroclimatological potential of trees, and thus proved the site's high dendroclimatic potential. This study highlights the potential of teak for the reconstruction of past climate.

***Keywords*:** Dendroclimatology, Teak Trees, Climate, Nilambur, Teak wood