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Climate Reconstruction on the Growth of Teak in Umphang Wildlife Sanctuary, Thailand

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ABSTRACT

Teak is an example of proxy data that can be used to indirectly deduce past climatic conditions. The objective of this study was to investigate the relationship between teak growth and climate data in western Thailand. Dendrochronological techniques were used to analyze 52 sample cores from Umphang Wildlife Sanctuary. The crossdated ring width data could be extended back 127 years (1886-2012). The relationship between ring-width index and climatic data indicated a positive correlation ($p<0.01$) with the current year total rainfall in March and June. Thus, only March and June data were used to reconstruct the annual ring width index which indicated a downward trend in the reconstructed rainfall. Considering the March and June average total rainfall, a wet period occurred in 1887-1895 and this gradually decreased to a stable pattern in 1927-1945 with a further decline to another stable level in 1957-1964. Similarly, the dry periods occurring in 1896-1926, 1946-1955, 1965-1981 and 1982-2012 could explain the high fluctuations in rainfall. Periods of 2.2-2.7 and 25.2 years were found to be common with the variations in the El Niño-Southern Oscillation. In conclusion, teak growth information can be used to monitor global warming events.

1. INTRODUCTION

Global warming is an important environmental issue worldwide that has impacted human well-being and contracting ecosystems, due to temperature changes. In particular, a trend of bouts of extreme weather and natural disasters affecting human activities and natural resources is beginning to transform life on Earth (IPCC, 2014). Several studies have presented scientific evidence that human activity may already be influencing climate. Thus, to understand, detect, and eventually predict human influences on climate requires comprehension of the systems that determine climate and of the processes that lead to climate change (IPCC, 2001). The analysis of climate variability can either be considered at a global scale or on a local scale (Da Motta, 2004; Mauro, 2004; Meyneek, 2004). In order to better understand climate change and climate variability, both from a natural and anthropogenic-induced origin, analyzing historical climate data and its behavior can give indications of what to expect in the future (Bradley, 2014).

An ever increasing demand for the reconstruction of paleoclimatic data relating to the climate of a given geologic time and information about natural disasters has stimulated scientists to extend the scope of their study from the southern and northern temperate zones to the equator, including Thailand (Tejedor et al., 2017; Wilson et al., 2017; Lumyai and Duangsathaporn, 2017; Palakit et al., 2015; Duangsathaporn and Palakit, 2013; Arrigo et al., 2011; Ram, 2010; Buckley et al., 2007a). During the past decade, Thailand has been experiencing the impact of climate variability related to monsoons, such as floods and droughts. These, in turn, have had an impact on production of agriculture products, especially rice. Now the time for planting rice has been shifted from late May to early May, and the rice is harvested in September, in order to avoid the risk of flooding in October, as an adaptation strategy in the face of prevailing climate variability (Reda et al., 2015). In fact, the record of climatic variability is rather short and not enough to explain long-term climatic changes and extreme events. Climate plays an important role in the existence of humans who have had to adapt and adjust to such changes. It is, therefore, important to know the impact of climatic variations. In recent years, forests, which are a valuable natural resource, have been drastically affected by climate variability, leading to difficulty in tree growth and yield management. Therefore, an understanding of the climate-growth response relationship is of prime importance. Tree-ring analysis, also known as dendrochronology, is the science that deals with dating and study of annual growth layers in wood and can be applied to study tree growth and identify the factors affecting its growth (Fritts, 1976). Tree-ring studies have gained interest of the researchers in Southeast Asia, especially over the past decade.

Teak (*Tectona grandis* L.f.) is one of the most well-known and valuable timbers in the world and is generally found in the natural forests of northern Thailand and is mainly grown in plantations. Several researchers have suggested that the growth of Thai teak is affected by several environmental factors, especially soil moisture, rainfall, and temperature (Sangram et al., 2016; Buajan et al., 2016; Muangsong et al., 2016; Palakit et al., 2015; Pumijumnong et al, 1995; Buckley et al., 2007b).

Dendroclimatologists have conducted successful studies on teak (*Tectona grandis*) located in India, Myanmar, Thailand, and Indonesia that are a valuable resource for dendrochronologic studies of climate response (Pumijumnong, 2013; Arrigo et al., 2011; Ram et al., 2010). The relationship between teak-growth rate and environmental factors could be used for sustainable management of teak both in natural forests and plantations. The objective of this study is to investigate the relationship between teak growth and climate variability at local scales and compare the impact of variability on teak growth at different sites and demonstrate the potential for climatic reconstruction in western Thailand.

2. METHODOLOGY

2.1 Sites selection

Tree-ring data used for this study was derived from a stand with lot of natural teak that had not been disturbed by human activity (within an approximate area of 4 square kilometers), growing in Umphang Wildlife Sanctuary (within an approximate area of 220 square kilometers), located in Umphang district of Tak Province, between 15º 33´ to 16º 23´ N latitude and 98º 33´ to 99º 07´ E longitude (Figure 1).

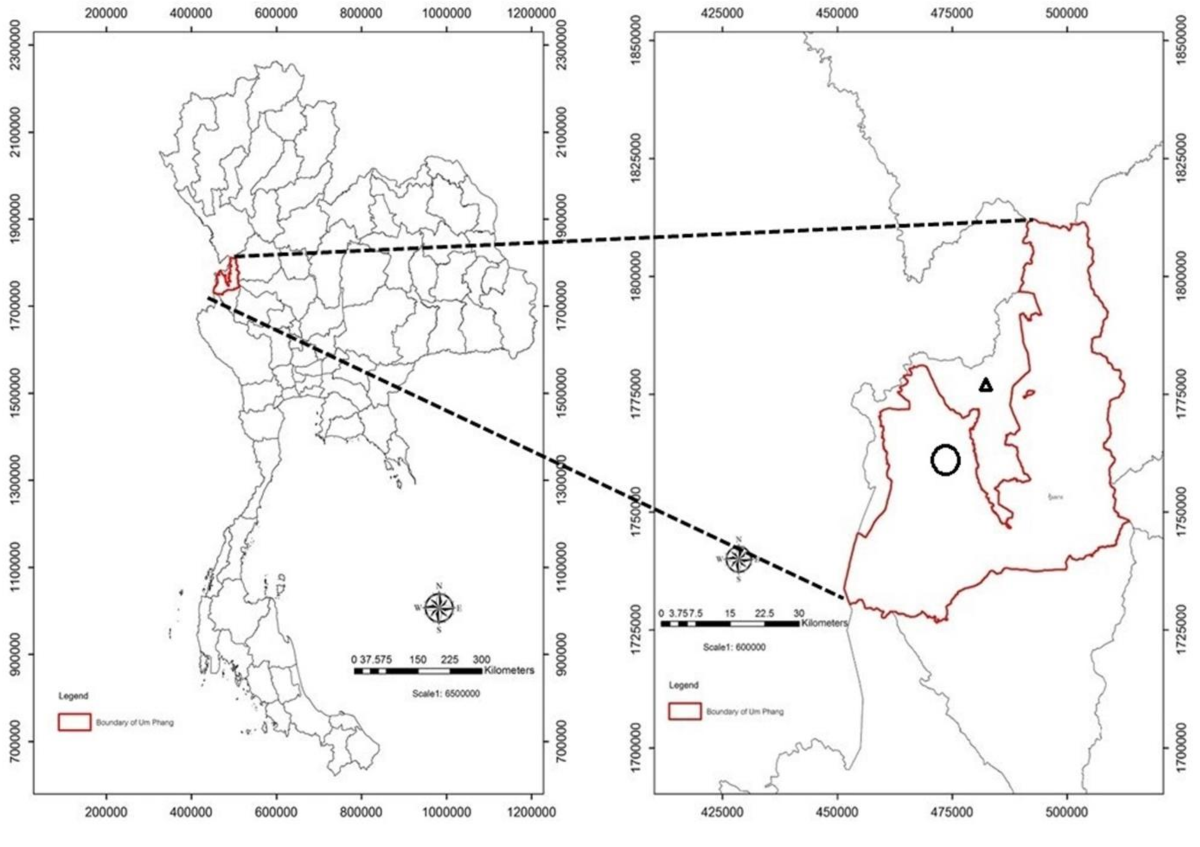

Figure 1. Map of Thailand showing the location of the *Tectona grandis* study site; black triangle indicates the Umphang meteorological station and the black circle points to the sampling location

The geographical features of the Wildlife Sanctuary consist of extensive and high mountains (altitude of 10-2,125 meters above the mean sea level). Mean annual temperature at study site during the years 1977 to 2012 is 20.7 ^{o}C and mean annual rainfall is 1483 mm. However, in the summer (March-May), the weather is relatively hot for short periods of time (average temperature of 26 ^{o}C with total monthly rainfall of 355.3 mm). In winters (November-February), the weather is cold (average temperature of 21.8 ^{o}C with total monthly rainfall of 50.5 mm). During the rainy season (June-October), the region experiences heavy rains (monthly rainfall is 1077.6 mm) (DNP, 2006). Local climatic data used, included average monthly temperature, total monthly rainfall, and average monthly relative humidity data, and were measured at the Umphang meteorological station which happens to be nearest (around 30 km from the study location) to the study site. This data has been published by the Thai Meteorological Department.

2.2 Teak specimens collection and field sample collection

Sixty increment core samples were collected in July 2013, from 30 living teak trees, using an increment borer, at a breast height of 1.30 m. Two incremental core samples were collected from each tree, in perpendicular directions (east-south) of the stems for each sample site. Dominant trees were selected for sampling to best target the oldest trees (largest DBH) in the stand. Trees with evident bruises, scars and other ill-effects such as fire or insect damage were avoided. All core specimens were dried, glued, and mounted on wooden supports with the cross-section pointing upwards. The tree-ring cross section could then be seen against the supported wood positioned at 90 degrees. Surface preparations were carried out using 1000-grit sandpaper until the boundary of each annual ring was clearly visible.

2.3 Ring width measurement and check for data accuracy

All cores were crossdated at the Laboratory of Tropical Dendrochronology (LTD), Faculty of Forestry, Kasetsart University, Bangkok, Thailand and the tree-rings were identified as annual rings, false rings, or missing rings by using the techniques of visual cross-matching (Fritts, 1976) and vessel size investigation (Palakit et al., 2015). After successfully crossdating, the total tree ring widths were measured using a 0.001 mm sliding stage micrometer using the TA Unisilide Tree-Ring Measurement System (Velmex Inc., New York, USA) interfaced directly to a microcomputer and a 4X-40X magnified stereo microscope, for recording the measurements. The accuracy of crossdating was subsequently checked with the COFECHA program (Holmes, 1983). The total ring widths were analyzed using the general statistical tools used in dendrochronological studies, namely series intercorrelation, standard deviation, and mean sensitivity (Fritts, 1976).

2.4 Tree-ring index construction

A variety of growth functions were used to fit to each of the sample core data. These functions, which indicated the relationship between tree-ring width and years, included the negative exponential equation. Standardized ring-width series, also called ring-width index, was obtained by dividing the ring-width with the value obtained from the fitted curve for a particular year (Fritts, 1976). Standardization of ring-width measurements is necessary to remove the decrease in size associated with age while other factors are removed by fitting a curve to each measured series (Fritts, 1976). Finally, the ring-width data was detrended and an autoregression was done using the program ARSTAN (Cook, 1985). The chronological signal strength was also evaluated in order to indicate the acceptable number of the population and to measure the average correlation between ring-width series, using the calculated expressed population signal (EPS) and the running RBAR, respectively (Wigley et al., 1984; Cook and Kairiukstis, 1990).

2.5 Relationship between tree-rings and climate, climate reconstruction, and spectral analysis

The correlation of local climatic data with the ring-width index was obtained using simple linear correlation and multiple linear regression, with data ring-widths as the dependent variable and climatic data as independent variable. The climate variables for the reconstruction were chosen on the basis of response function. The data were divided into an early period and a latter period in order to assess the temporal model stability of the identified underlying model. Calibration-Verification statistics commonly used in dendroclimatology (Cook and Kairiukstis,

1990) were calculated to confirm the model reliability. The statistics included Pearson's correlation coefficient (R), the coefficient of determination (R^2), the verification reduction of error statistic (RE), the verification coefficient of efficiency (CE), the product means test (Pmt), and the sign test (ST) (s being number of incorrect signs) (Fritts, 1976; Cook et al., 1994). The tests were computed using the verify routine (VFY), available in the Dendrochronology Program Library (DPL) software (Holmes, 1994). Spectral analysis (Jenkins and Watts, 1969) was used to evaluate the frequency domain properties of the reconstruction using The REDFIT procedure (Schulz and Mudelsee, 2002).

3. RESULTS AND DISCUSSION

3.1 Chronology development

In Umphang Wildlife Sanctuary, a total of 52 cores from 26 trees were successfully crossdated out of a total of 60 cores from 30 trees. The crossdated ring width data could be extended back to 127 years from 1886-2012 (Figure 2(a)). Series intercorrelation, average mean sensitivity, mean standard deviation, and the mean autocorrelation obtained from COFECHA program were 0.412, 0.392, 1.505 and 0.612, respectively. The ring-width data were applied to detrend and autoregress using a negative exponential equation. Standardized ring-width series, also called ring-width index, were obtained by dividing the ring-width by the value obtained from the fitted curve for a particular year (Cook and Peters, 1981; Fritts, 1976). These procedures were done by using ARSTAN program (Cook, 1985). The ring-width index indicated a rapid growth during 1930-1953 and a continuous decrease until 1973. The later growth rate seems to be stable until the present time (Figure. 2(b)). We quantified the chronology signal strength using the expressed population signal or EPS (Wigley et al., 1984), which indicates how well the study site chronology estimates a theoretically infinite population. The part of chronology, where replication (n) was adequate to accomplish an EPS ≥ 0.85 was accepted as reliable chronology for tree-ring analysis, and was regarded as dependable proxy for climate reconstruction. The running RBar (Cook and Kairiukstis 1990), which measures correlation between ring-width series through time, was also calculated (Figure 2(c)).

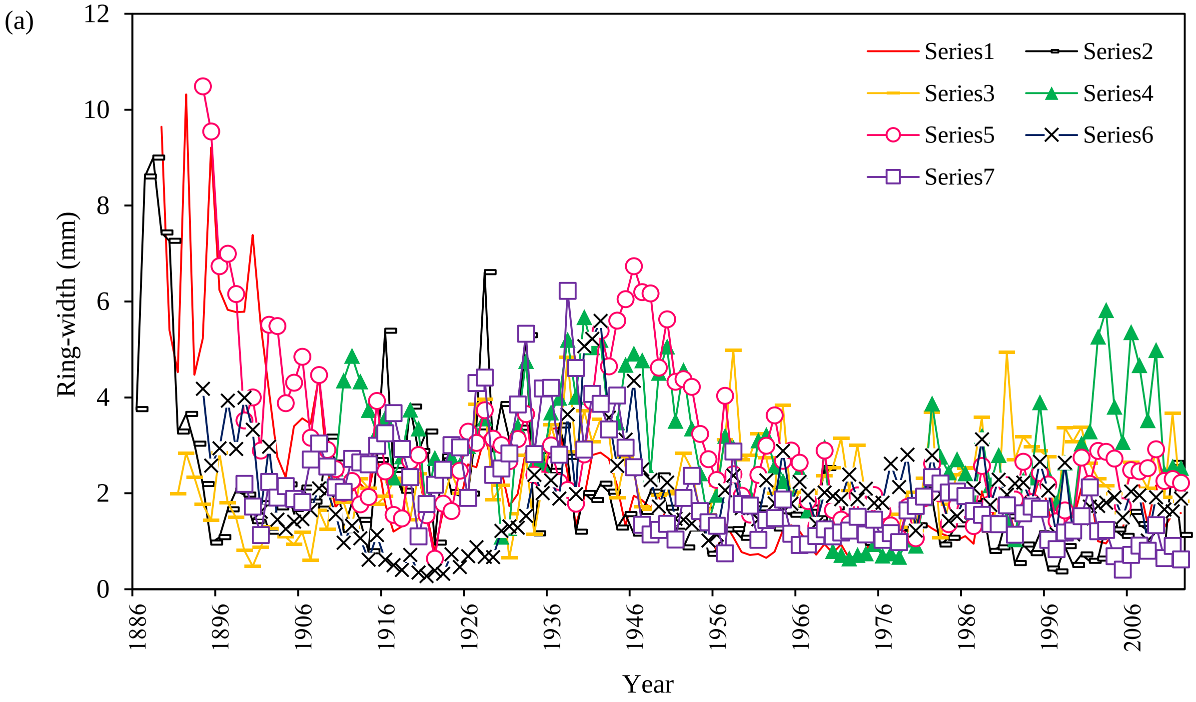

Figure 2. (a) Average ring-width of teak in the Umphang Wildlife Sanctuary. (b) The standardized chronological index (plot in continuous line) and its 10-year moving average (plot in dashed line). (c) Running EPS statistic and Rbar of Umphang tree-ring index which was accepted as a reliable chronology for tree-ring analysis.

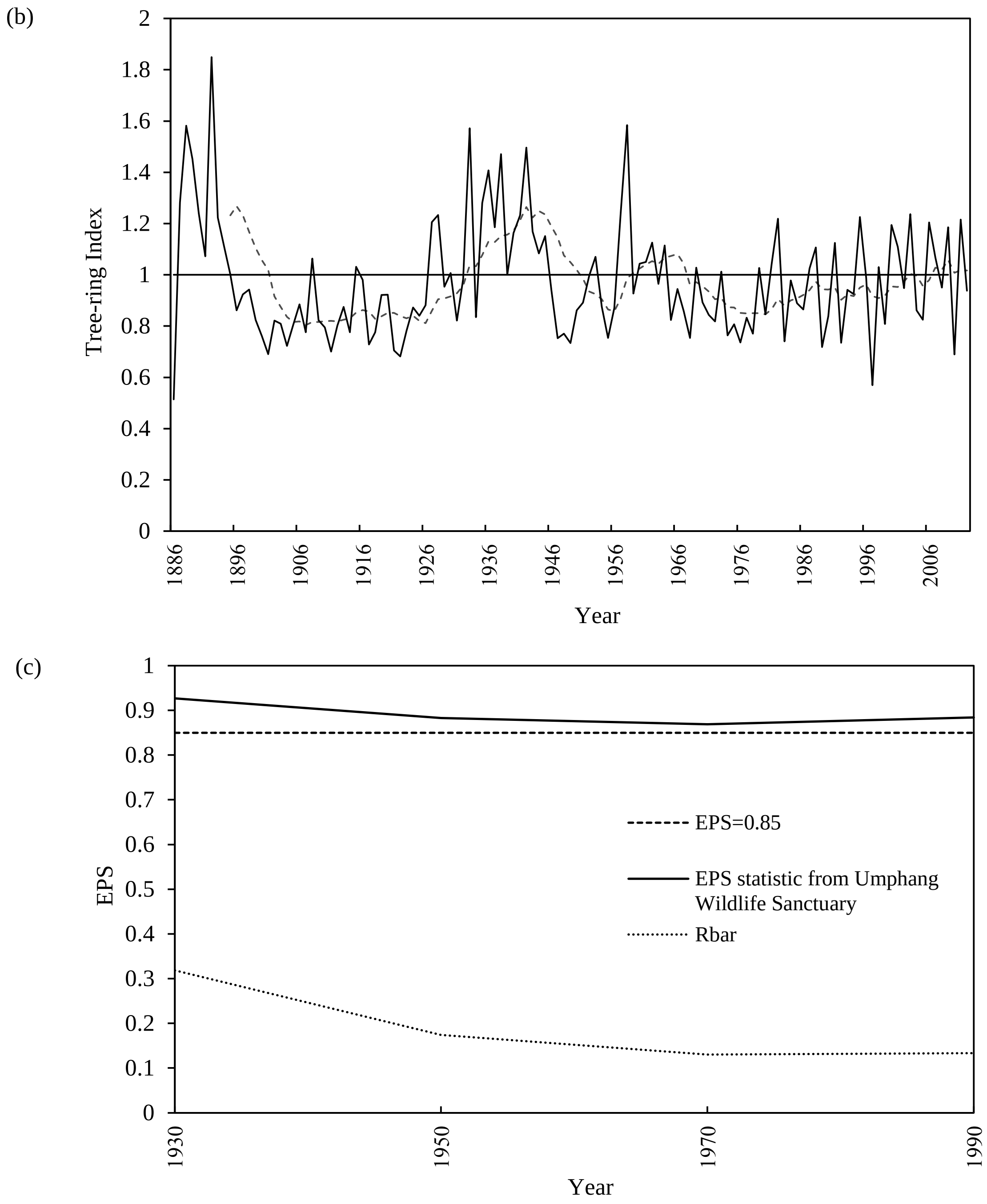

Figure 2. (a) Average ring-width of teak in the Umphang Wildlife Sanctuary. (b) The standardized chronological index (plot in continuous line) and its 10-year moving average (plot in dashed line). (c) Running EPS statistic and Rbar of Umphang tree-ring index which was accepted as a reliable chronology for tree-ring analysis (cont.).

3.2. Climate response

Thirty-six years of climatic data (available during a period from 1977-2012), including average monthly temperature, total monthly rainfall, and average monthly relative humidity data, were obtained from the Umphang meteorological station in Umphang district in Tak province. These data were published by Thai Meteorological Department and are plotted in Figure 4(a). Correlation coefficients for rainfall, temperature, and relative humidity from 1977-2012 indicated a strong significant positive correlation ($p<0.01$) with the current year total rainfall in March and June (Figure 3). The Umphang chronology indicated a significantly positive correlation with the current yearly rainfall (R^2 = 0.214) (Figure 4(b)) and a strong significant positive correlation ($p<0.01$) with the current year total rainfall in March (R^2 = 0.274) and the total rainfall in

March and June (R^2 = 0.404) (Figure 4(c)). The data were also split into narrow ring and wide ring against minimum and maximum rainfall and temperature. In this case, the wide ring showed a significant positive correlation ($p<0.05$) with the total yearly rainfall. Regarding the current year minimum temperature, the Umpang chronology indicated a significant positive correlation ($p<0.05$) with total yearly rainfall and a negative correlation with average yearly temperature.

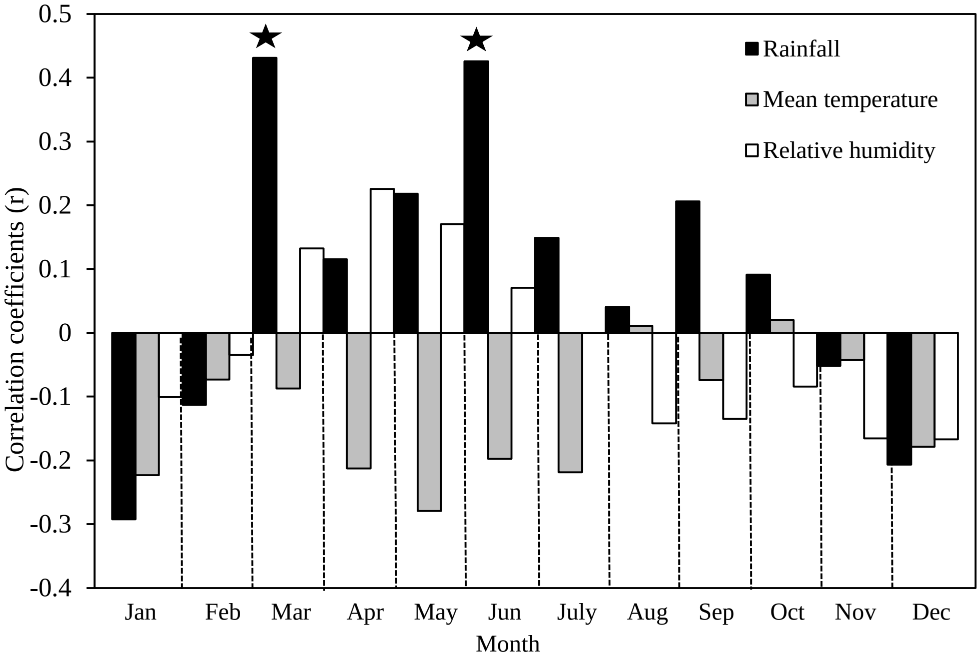

Figure 3. Correlation coefficients between average monthly temperature, total monthly rainfall, and average monthly relative humidity data and tree-ring index. Correlation coefficients for rainfall, temperature, and relative humidity from 1977-2012 showed a strong significant positive correlation ($p<0.01$) with current year total rainfall in March and June. Stars represents significance at 1% level.

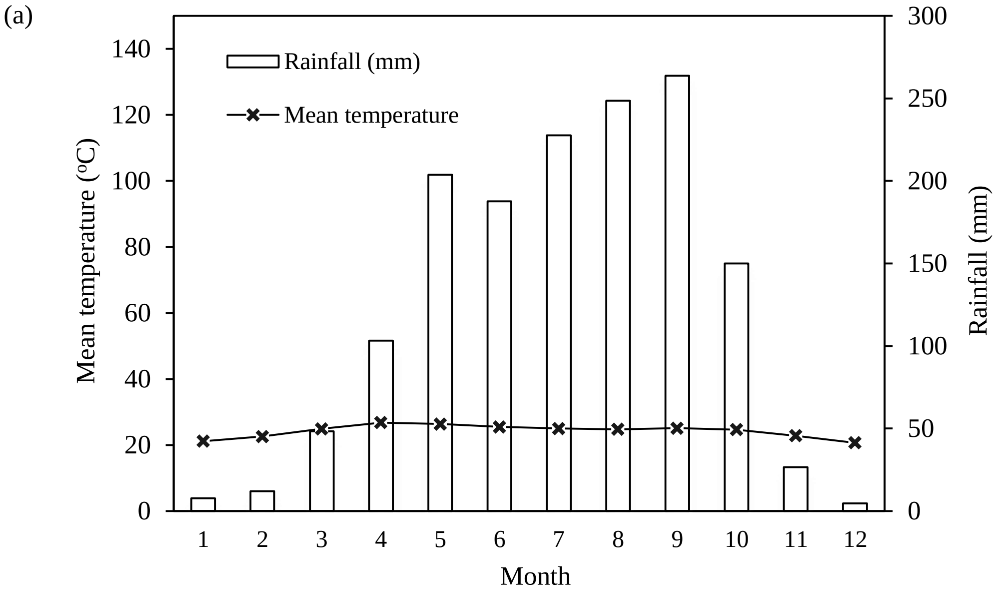

Figure 4. Climate-Growth relationships in Umphang Wildlife Sanctuary. (a) Climate data that were published by Thai Meteorological Department. (b) The Umphang chronology which indicated a significantly positive correlation with the current yearly rainfall for the period 1977-2012 and (c) a strong significant positive correlation ($p<0.01$) with rainfall in March and June.

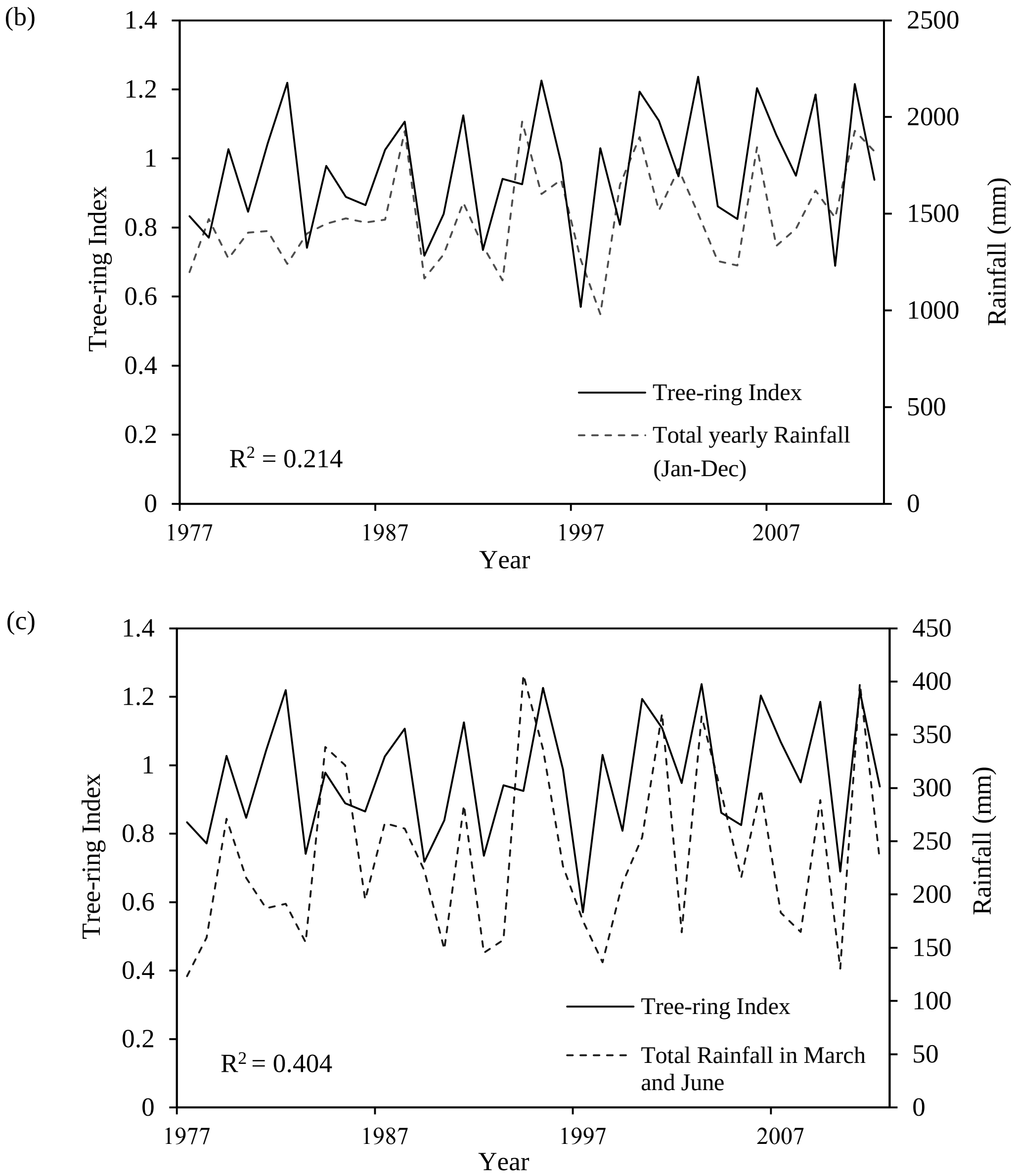

Figure 4. Climate-Growth relationships in Umphang Wildlife Sanctuary. (a) Climate data that were published by Thai Meteorological Department. (b) The Umphang chronology which indicated a significantly positive correlation with the current yearly rainfall for the period 1977-2012 and (c) a strong significant positive correlation ($p<0.01$) with rainfall in March and June. (cont.)

3.3. Climate reconstruction and spectral analysis

The variations in annual ring width of teak was related to temperature, rainfall and relative humidity, but exhibited the highest significant relationship with rainfall. The results revealed that the current year rainfall in March and June was the most important factor affecting tree-ring widths. Therefore, we chose the rainfall data during March and June as the main variable for the reconstruction of precipitation data. The data was split into an early period (1996-2012) for calibration and a late period (1977-1995) for verification (Figure 5). Linear regression was used to calculate the transfer function for rainfall in March and June as reconstructed from the tree ring chronology (1977-2012). The resulting rainfall reconstruction model can be mathematically expressed as

$$\hat{Y}_t = 256.02Xt - 10.58 \qquad (R^2 = 0.312) \qquad (1)$$

Where: $\hat{Y}_t$ is the estimated March and June rainfall value and Xt is the corresponding tree-ring index value obtained every year (t).

The measured and reconstructed data were compared and the calibration-verification statistics were calculated. The statistics of the calibration period showed an r = 0.64 (p<0.01), RE = 0.42, PM = 2.56, and s = 4. The statistics during the verification period indicated an r = 0.46 (p<0.05), RE = 0.22, PM = 1.22, and s = 5. Using the reconstruction model (Equation 1), we reconstructed the rainfall during March and June from 1886 to 2012. The reconstructed rainfall in March and June showed an average rainfall of 239.1 mm. Trends in the reconstructed rainfall indicated wet periods that occurred during 1887-1895, increased to 325.4 mm and gradually stabilized, and in 1927-1945 and 1957-1964 increased to 289.2 mm and 278.8 mm, respectively, with dry years occurring in 1896-1926, 1946-1955, and 1965-1981, and that the years 1982-2012 exhibited large fluctuations in rainfall. (Figure 5).

The spectral analysis of the reconstructed rainfall in March and June using the tree-ring index revealed significant periods in a band of 2.2-2.7 years. A strong peak around 25.2 years can also be observed, which may be due to the influence of ENSO index (Figure 6).

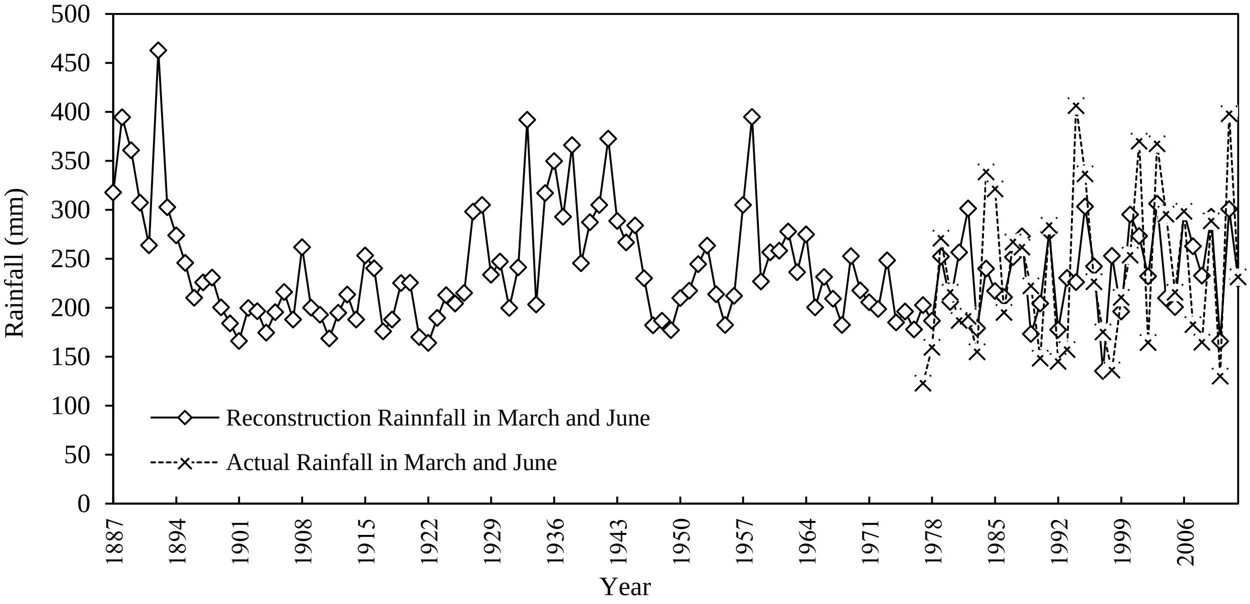

Figure 5. Reconstructed rainfall in March and June

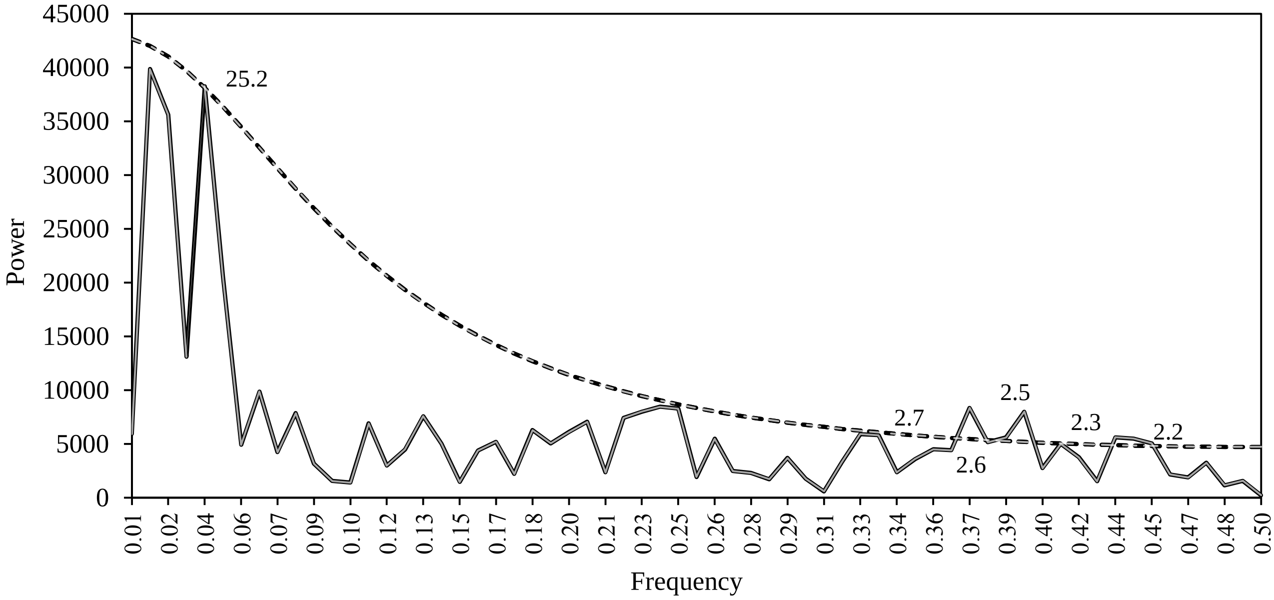

Figure 6. The power spectral for reconstructed rainfall during March and June using the REDFIT procedure. Peaks above the dotted line are deemed significant at a 95% level of confidence (p<0.05).

4. CONCLUSIONS

Using data obtained from the teak growing in the Umphang Wildlife Sanctuary, we constructed a tree ring index and used it as a proxy to analyze the climate variables in the surrounding region. It was found that the present year average rainfall in the beginning of the rainy season (March-June) showed a positive correlation with the ring width index for teak. Sinha et al. (2017) and Bhattacharyya et al. (2007) studied teak wood vessels in India and found that climate during the months of April and June (the beginning of the rainy season), of the current year, is especially important for early wood vessel formation. This result is similar to that reported in the previous studies initiated in Thailand by Pumijumnong et al. (1995) and Buckley et al. (2007). Pumijumnong et al. (1995) showed that the growth of teak was significantly correlated with the rainfall from April to June and was insignificantly correlated with temperature, while Buckley et al. (2007) constructed a 448-year teak chronology from data obtained in the northwestern part of Thailand (Mea Hong Son Province). They suggested that the growth of teak was significantly correlated with soil moisture availability (PDSI) and rainfall during the monsoon season and spectral analyses revealed power in the ENSO series in periods ranging from 2.2 to 4 years, and at the multi-decadal scale at 48.5 years. Several researchers have found that teak growth is positively correlated with April-August rainfall and the Palmer Drought Severity Index variability in Myanmar, during and prior to the May-September monsoon season (Arrigo et al., 2011). Ram et al. (2010) reported that teak from three different tree sites in Central India showed a significant positive relationship between April-September moisture index and tree-ring chronologies for the period of 1901-2000. For the reconstructed climate data of 127 years during March and June from the Umphang Wildlife Sanctuary index, the reconstructed rainfall indicates an average rainfall of 239.1 mm. The trends in reconstructed rainfall showed wet and dry period years which could explain the high variability in rainfall and that anomalous events occurring in some growing years indicated to an increased rainfall. It was also noted that the variations had significant power in the periods of 2.2-2.7 years and 25.2 years, respectively. There are, however some limitations to the present study with the tree-ring index extending back only to the year 1886, which is not enough to comment on any long term climate variations. Future extensive field survey for the collection of stump teak trees will help extend this chronology. From the present analysis, we conclude that signals obtained from the growth of teak in the Umphang Wildlife Sanctuary could be applied to monitor climate change and global warming events.

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