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Teak Tree Ring Widths: Ecology and Climatology Research in Northwest Thailand

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Abstract

There are only a few tree species in tropical zones showing the potential for conducting dendrochronology as tropical zones have been the target of logging concessions for a long time. Therefore, there are obstacles to the study of tree rings in these areas where full-grown trees with a significant tree ring width are scarce.

Nevertheless, this study attempts to select living teak trees from an elevation range of 100-600 m above the sea level (a.s.l.) from Mae Hong Son province, Northwest Thailand. The study sites are isolated. Our research aims to investigate growth, synchronise data between sites, and understand how teak tree ring width responds to ecological position and climate. In this study, we divided the study-site into 5 sites, each site covers different elevation except sites 4 and 5, which are the same elevation. The results revealed that the high correlation amongst the five sites chosen indicates the influence of a common force on the tree growth. The climatic response of teak growth showed that rainfall from the previous December to the next monsoon, March to July, in the current year, directly influences teak growth and, in turn, is negatively correlated with the temperature during the same period. Our results suggest that the teak network in Mae Hong Son province can be used as a high resolution proxy for drought and rainfall reconstruction in northwest Thailand.

Keywords: Teak, Thailand, ecology, climate response.

Introduction

The countries situated in the tropical and subtropical belt are often characterised by a high density of population, for which the main source of income is agriculture. Such countries rely heavily on water availability and rainfall and are particularly affected by climate change phenomena, possibly leading to agricultural crises and increased vulnerability of the society (Döll, 2002; Yusuf and Francisco, 2009). Efficient plans to mitigate such effects and to persistently ensure water supply require a deep understanding of climate patterns. Therefore, climate data are urgently needed not only for the present time but also for the past.

Trees have been proven to be suitable archives for such proxy data when instrumental records of rainfall and temperature are either short or are entirely missing (Mann et al., 2008). In recent decades, the long-standing paradigm that tropical trees do not form annual growth rings has significantly changed (Worbes, 2002) and the potential for tree-ring research was realised and repeatedly confirmed by wood anatomical and dendrochronological studies around the globe (Bormann and Berlyn, 1981; Baas and Vetter, 1989; Eckstein et al., 1995; Eckstein and Baas, 1999).

In Southeast Asia, the existence of annually formed growth rings has been taken for granted for at least 100 years, e.g., by Brandis (Liese, 1986), who worked on teak in India. Teak is naturally distributed from India to Myanmar, including in Thailand, Laos and Indonesia (Lamprecht, 1986). Teak is amongst the most promising tree species for monsoon climate reconstruction. Unfortunately, because of its highly appreciated timber quality, teak has been logged for commercial purposes for a long time. Therefore, the majority of living teak trees are currently rather young. Nevertheless, we were

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able to find abundant living teak trees, which we used in this study to reconstruct the May-July rainfall for Northwest Thailand.

Materials and Methods

Study area and sample collection: The study area is located in a mountainous chain along the Kong River; this area is in the Pai wildlife sanctuary. We found abundant natural teak, which was left after logging and grew from the bottom to the top of the mountain. The teak ecosystem can be grouped into 5 sites. Site 1 covers 100-300m a.s.l. and includes 21 trees, from which 42 cores were taken; the average diameter at the breath height ranged from 150 to 349cm, and the soil moisture content at a 20cm depth was 42.7%. Site 2 covers 300-400m a.s.l. including 20 trees, from which 40 cores were taken; the average diameter at the breath height ranged from 193 to 304cm, and the soil moisture content at a 20cm depth was 39.3%. Site 3 covers 400-500m a.s.l. and includes 21 trees, from which 42 cores were taken; the average diameter at the breath height ranged from 175 to 342cm, and the soil moisture content at a 10cm depth was 16.2%. Site 4 covers 500-600m a.s.l. and includes 25 trees from which 50 cores were taken; the average diameter at the breath height ranged from 171 to 338cm, and the soil moisture content at 20cm was 30.7%. Site 5 covers 500-600m a.s.l. and includes 22 trees, from which 44 cores were taken; the average diameter at the breath height ranged from 165 to 332cm and the soil moisture content at a 20cm depth was 33.5% (Fig. 1). The samples were taken in January 2010, which is the dry season in Thailand. The soil moisture content in each study area is rather high. It appears that the soil moisture is not the limiting factor for teak growth because it is close to the Kong River.

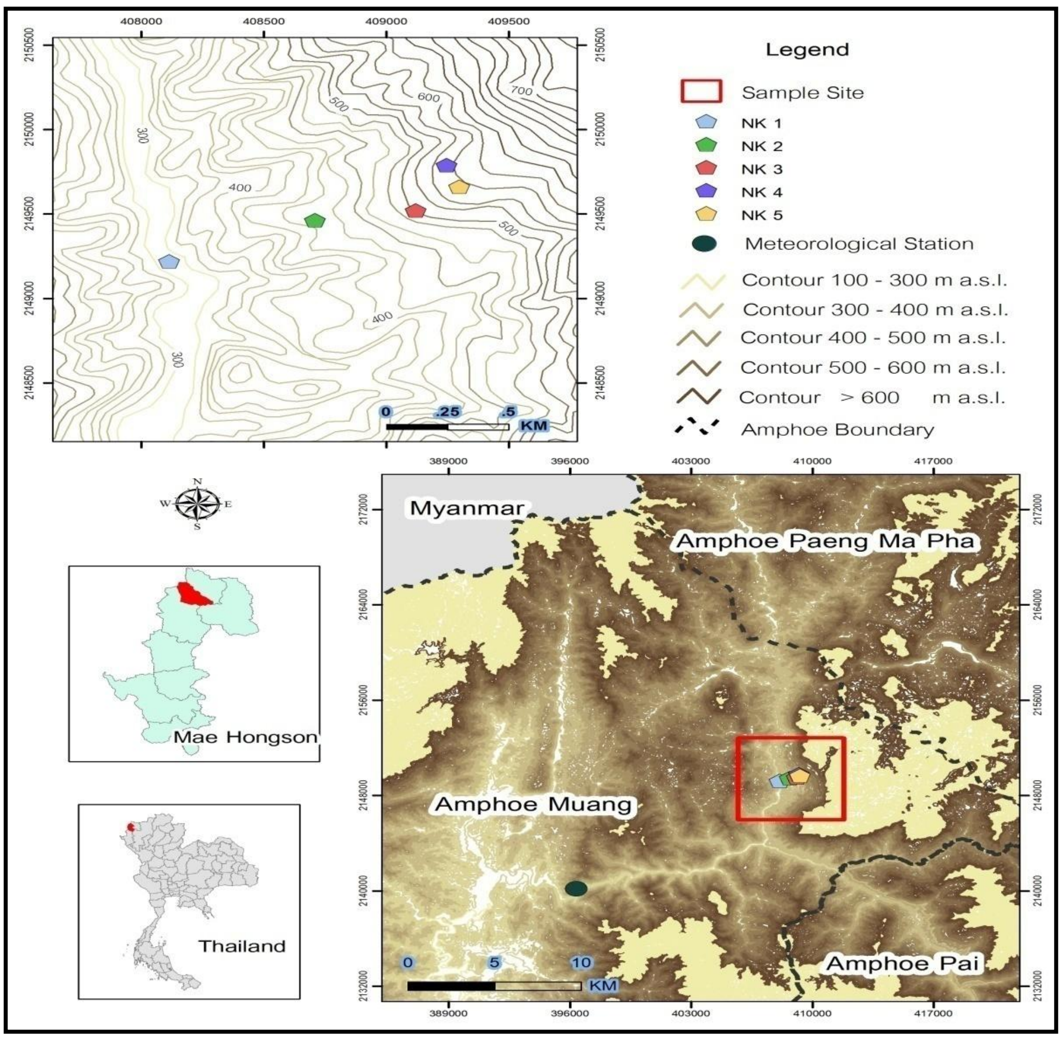

Fig. 1. Map of the study area.

Fig. 2. Teak sample collection

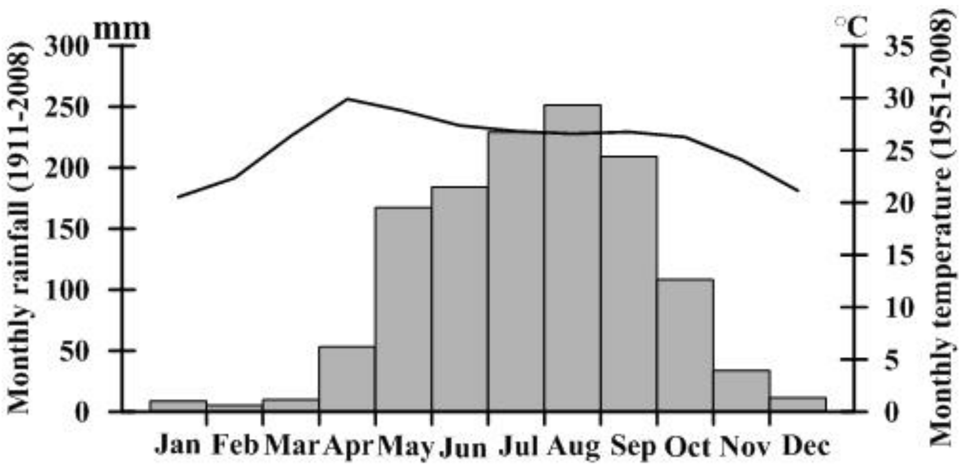

Fig. 3. Climate diagram for Mae Hong Son Province

Dendrochronological techniques were used for sample preparation and measurement (Fig. 2), and cross dating was checked on the light table and confirmed with the COFECHA program (Holmes et al., 1986). The Arstan program was used for fitting a 66-year spline function to each tree-ring series to eliminate the age trend (Cook, 1985). Finally, the series were averaged for each site to create a master site chronology using a robust mean function, because the Site chronology (Master Index) turned out to reflect a large amount of common variation at each site. Then it was correlated with Mae Hong Son climate data using the program Dendroclim 2002 (Biondi and Waikul, 2004). Mean monthly rainfall data at Mae Hong Son Meteorological station, which is the closest meteorological station (approximately 30km southwest of the study sites) range of 1911-2008 and the mean monthly temperature range of 1951-2008 were used (Fig. 3). The strong climate signal reflected in the Master Index was reconstructed as far back as the expressed population signal (EPS) of all the tree-ring series, indicated ≥ 0.85 (Briffa and Jones, 1990). We also compared the Master Index with the 2.5° x 2.5° gridded months Palmer Drought Severity Index (Palmer 1965). Finally, the spectra power derived from the Multi-Taper method was analysed.

Results and Discussion

NK1 has the longest teak tree ring index (137 years), which is from 1872 to 2009. The shortest teak tree ring chronology (112 years, 1898-2009) was from NK3. The teak tree ring index from each site and the site chronology are demonstrated in Fig. 4. To understand the role of the climate on the teak tree-ring width, 15 months were selected, starting from October of the previous growth year to December of the current growth year. The Mae Hong Son climate data includes from 1911 to 2008 for rainfall and 1951 to 2008 for temperature. A high correlation between the teak residual chronology and the climate data was found at each site. We present some descriptive statistics in Table-1. The significant positive relationships of rainfall with the teak tree ring indices observed over the five sites and the master site chronology (Fig. 5) indicate an important role of rainfall in tree-ring variation. The amount of rainfall from the transition monsoon months (March-July) is a critical factor that influences teak growth. In turn, teak indices show a strong negative relationship with temperature during the same period. Our results agree with previous studies of teak dendrochronology in Thailand (Pumijumnong et al., 1995, Buckley et al., 2007) and in Myanmar (Pumijumnong et al., 2001). Teak in Thailand appeared to respond to rainfall earlier than India teak, which was found to respond to rainfall in June through September of the current year (Shah et al., 2007; Ram et al., 2008).

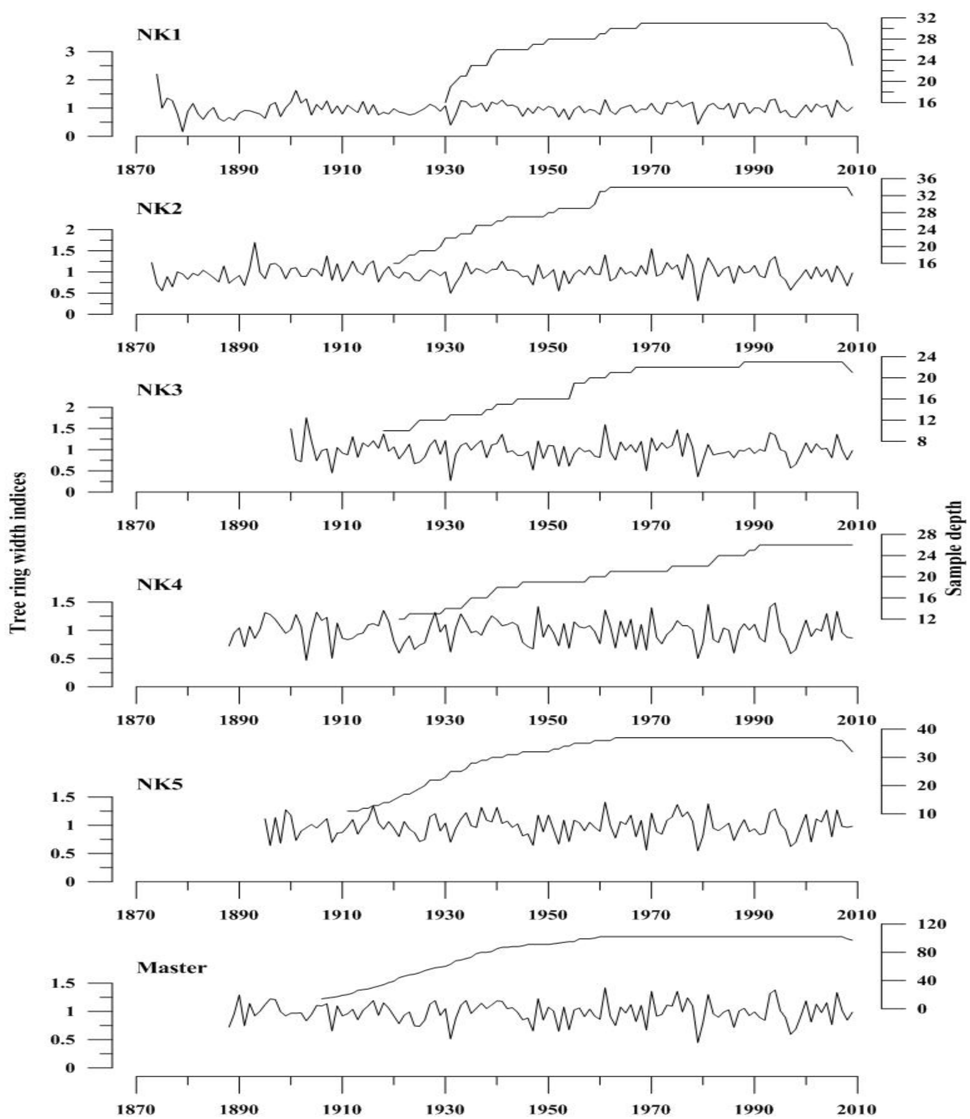

Fig. 4. Teak site chronologies index and master chronology with sample depths

Table 1. Descriptive statistics of Teak chronologies

Sites	Tree (n)	Core (s)	year	Time-span	Mean sea level	Mettle tree-ring width (mm)	Standard deviation (SD)	Mean sensitivity	Auto correlation	Correlation between trees	Variation in 1 eigenvector (%)
NK1	20	31	137	1872-2009	100-300	3.32	1.76	.359	.602	.26	31.95
NK2	18	34	134	1875-2009	300-400	2.71	1.53	.356	.636	.26	31.89
NK3	15	23	112	1898-2009	400-500	2.73	1.25	.357	.522	.40	44.96
NK4	16	26	123	1887-2009	500-600	2.82	1.53	.348	.654	.33	37.50
NK5	21	37	116	1894-2009	500-600	2.70	1.52	.321	.698	.34	37.76
Master Index	69	102	123	1887-2009		2.87	1.51	.338	.636	.30	32.92

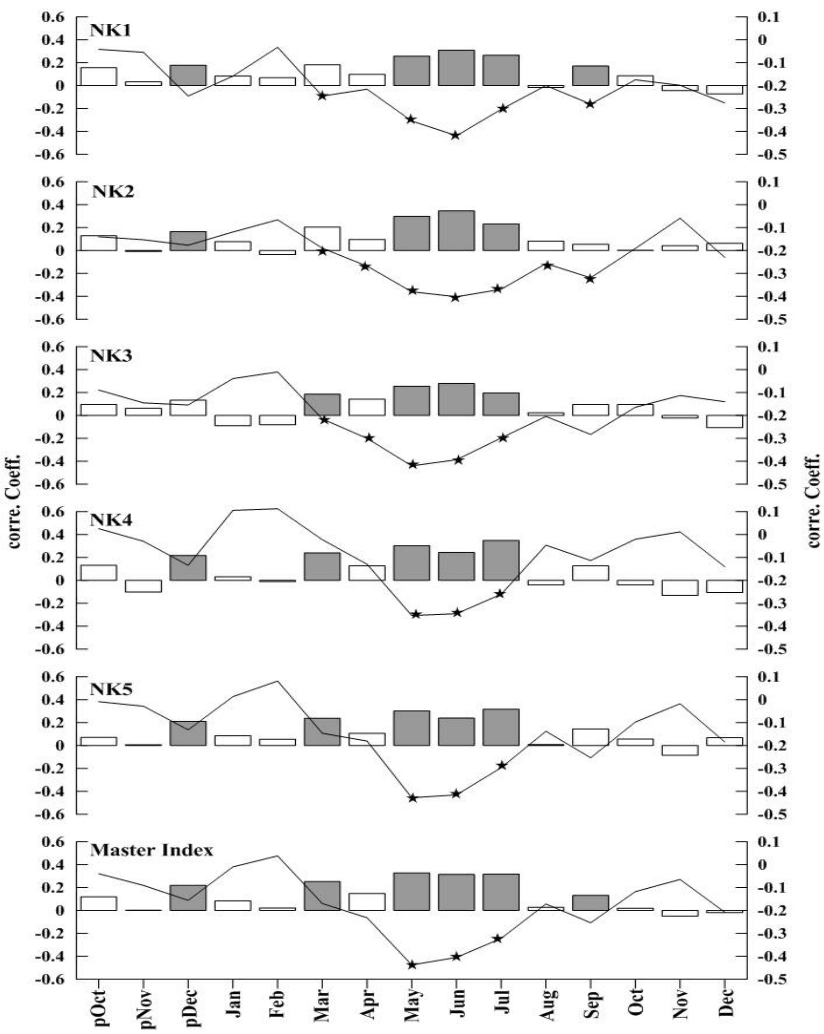

Fig. 5. The correlation coefficient between the teak tree ring index and the temperature (line) and rainfall (bar); the grey bar and asterisk indicate correlations that are significant at p<0.05

Teak in the Mae Hong Son province has a significant positive relationship with March and May to July rainfall, whereas temperature has a minor influence. This scenario confirms earlier results for teak in other parts of Thailand (Pumijumnong, 1995; Pumijumnong et al., 1995; Borgaonkar et al., 2001; Buckley et al., 2001; Palakit, 2004) and in Myanmar (Pumijumnong et al., 2001; Kyaw, 2003). However, our result is different from the output in India, where teak growth has a significant positive correlation with rainfall from the previous October (Bhattacharyya et al., 1992). Teak in Indonesia has shown a significant positive relationship with the weather conditions during the transition from the dry season to the wet season (Jacoby & D'Arrigo 1990). In Thailand, it is obvious that the first rainfall, which occurs from a southwest monsoon that brings moisture from the Andaman Sea from May through October, has an influence. Two important factors for teak trees to build annual rings are genetic control and external factors, especially the amount of rainfall. The temperature fluctuates little throughout the subtropics. This scenario is found not only for teak tree-ring widths but also for teak anatomical features and cambium activity (Pumijumnong, 1997). The results showed that teak cambial onset (differing by location) took place during the last week of April to the end of May, which coincided with the first moisture at the beginning of the rainy season.

Master Index and May-July Rainfall Reconstruction

The Namkong master chronology was used in a straightforward manner as a direct proxy for the early monsoon (May-July) weather conditions. Table 2 explains the statistics for the two periods of calibration (1911-1957) and verification (1958-2008), and vice versa. All of the statistics are significant ($p<0.05$). Even though the R^2 is rather small, the reduction of error (RE), the correlation coefficient (CE) and the sign test are positive. A positive RE and CE are evidence for a valid regression model (Cook et al., 2000). In addition, the values of the sign test indicate the correct sign in the reconstruction (Fritts, 1976). Fig. 5 shows the reconstructed May-July rainfall (the first half of the rainy season). An 11-year low-pass filter gives interdecadal variability in the reconstruction. We highlight the low-frequency variation in the warm/dry versus the cool/wet period as far back as 1888 A.D. using an 11-year low pass filter superimposed on the highly fluctuating annual value. There were four dry episodes, namely in 1996-1998, where the tree index is 0.8, 0.5 and 0.6, respectively, and especially in 1987, which had a rainfall of only 127mm (1997-1998 was recorded as a strong El Niño year). In 1979, the teak index is 0.5 and the rainfall is 117mm. In 1931, the teak index is 0.5 and the rainfall is only 99mm. During the long drought period of 1920-1926, the teak index is 0.9-0.8 and the range rainfall is 134-174mm, compared to the average of May-July from 1911-2008, which is 193mm.

Table 2. Reconstruction of May-July Rainfall

statistic	Calibration	Verification	Calibration	Verification	Full
	1911-1957	1958-2008	1958-2008	1911-1957	1911-2008
Variation explained	30.79%		11.27%		17.80%
R	0.555*	0.336*	0.336*	0.555*	0.422*
R^2	0.308	0.113	0.113	0.308	0.178
RE	0.308	0.045	0.113	0.245	
CE	0.308	0.021	0.113	0.220	
Sign test	32/15	32/19	32/19	39/18	

***significant p<0.05%; normally, RE>CE; and CE>0**

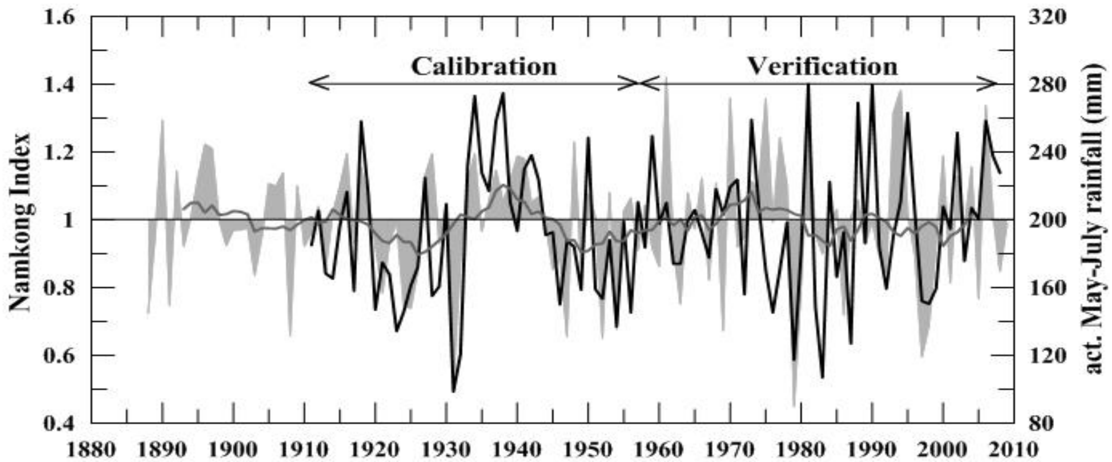

Fig. 6. **Actual May-July rainfall measurements (1911-2008) and high frequency as well as superimposed 11-year low-pass-filtered Namkong index as a proxy variable for monsoon weather conditions (1911-1880)**

Master Index and Palmer Drought Severity Index (PDSI)

We compared our Master index with the PDSI. The results showed that the positive correlation between the current year (January-December) and the prior year (October-December) was not significant (Fig. 7). Buckley et al. (2007) found a significant positive correlation between the Mae Hong Son index (MHS) and the PDSI. The difference between our research and the Buckley research was that our teak chronology is rather young and close to the river Kong, therefore, the moisture content did not limit the growth in our study sites. Buckley et al. (2007) obtained a strong drought in the teak chronology in the early and mid-1700s. D'Arrigo et al. (2011), investigated Myanmar teak and found that teak growth was positively correlated with rainfall and PDSI during and prior to the May-September rainfall.

The spectral power of the Master index record (Fig. 8) derived from the Multi-Taper method showed significance ($p<0.05$, $P<0.1$) in the range of ENSO variability spanning 2.14 – 5.3. Our teak chronology did not reflect the decadal scale variance that Buckley et al. (2007), obtained from their teak.

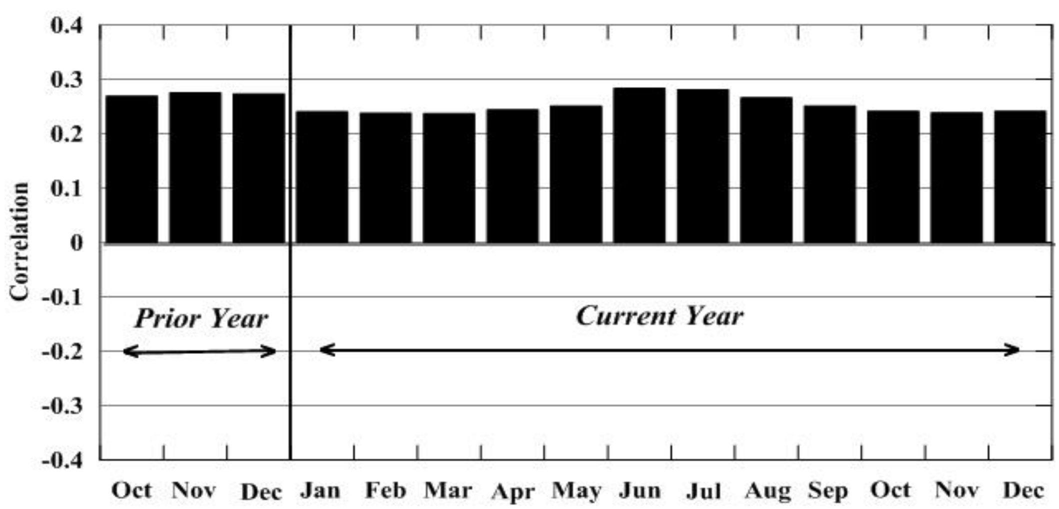

Fig. 7. **Correlation coefficient (bar) between the Namkong index and the regional PDSI (1948-2000)**

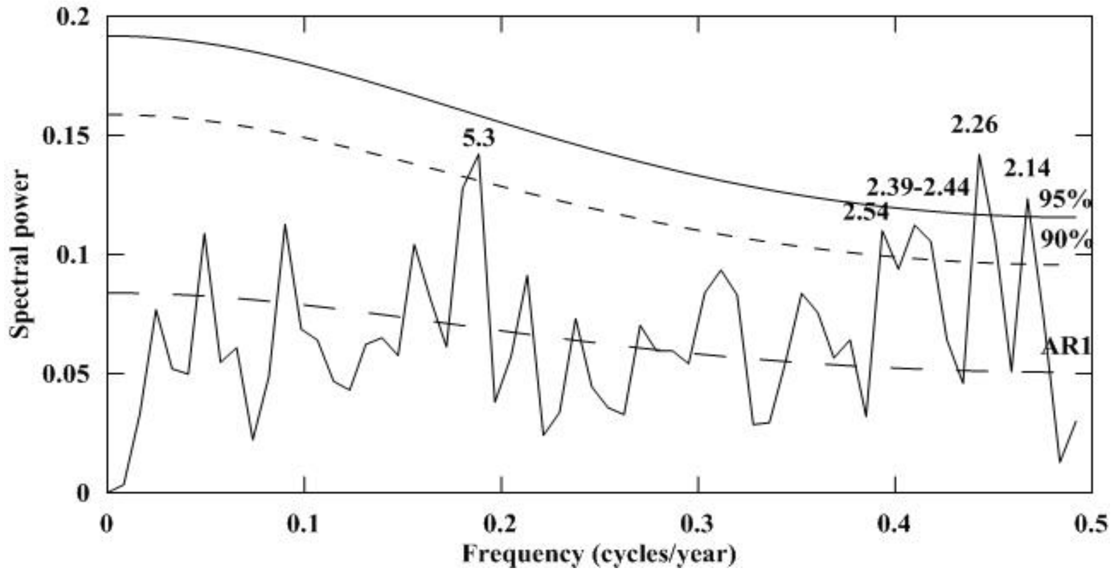

Fig. 8 Multi-Tape method power spectra for the Namkong chronology. The peak above the solid line indicates significance at the 95% level, and the dotted line indicates the 90% level

However, with respect to the factors that influence drought in Mae Hong Son province, it is not clear whether the climate variability itself or the El Niño influence on the climate is responsible for that drought. In general, the rainfall in Thailand is influenced by the southwest monsoon that brings moisture from the Andaman Sea and the Indian Ocean starting from May to the end of October. Nakamura et al. (2009) found that prior to the Indian monsoon, rainfall was mainly controlled by ENSO but during the second half of the twentieth century, since 1980 – the Indian monsoon activities – rainfall has been increasing by the Indian Ocean Dipole (IOD). Therefore, it is anticipated that drought or flooding, in Thailand, may have multiple interrelated causes, which should be investigated in detail.

Conclusions

Teak has been proven to be a promising dendrochronological tree species in a monsoon climate. A significant positive correlation between teak growth and rainfall in March-July of the growing season and a significant negative correlation between teak growth and the temperature in the same period have been confirmed. These results indicate that the teak index will have a value for a proxy climate reconstruction in Southeast Asia; an extended teak index could be generated from teak wood coffins and old houses, which could extend teak chronologies beyond their present limit of three centuries.

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