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Tree ring analysis of teak (*Tectona grandis*) ring width chronology from Mae Na, Thailand

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ABSTRACT

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Tree ring analysis of about 39 core samples of teak (*Tectona grandis*) collected from undisturbed natural forest near Mae Na, Thailand was carried out. All samples show good cross matching within the tree and between the trees. Chronology statistics indicate the usefulness of the species in dendroclimatic studies. Tree growth – climate relationship based on correlation and response function analysis revealed the important role of precipitation during the monsoon months.

Key-words—Teak, *Tectona grandis*, Tree ring, Thailand.

थाईलैण्ड के माए ना नामक स्थान से प्राप्त एक टीक वृक्ष (*टेक्टोना ग्राण्डिस*) के वलयी चौड़ाई कालानुक्रम का वृक्षजलवायुविक विश्लेषण

एच.पी. बोरगाँवकर, नासूदा पूमिजुमनांग, ब्रेन्डन.एम. बकले, ओ. तीसुमृति एवं एस. चुटीवाट

सारांश

उत्तरी थाईलैण्ड के माए ना नामक स्थान के समीप के अविक्षुब्ध प्राकृतिक वनों से संग्रहीत किए गए टीक (*टेक्टोना ग्राण्डिस*) के लगभग 39 क्रोड़ नमूनों का वृक्ष वलय विश्लेषण किया गया। सभी नमूने वृक्ष के भीतर तथा वृक्षों के मध्य उत्कृष्ट परस्पर सुमेलन प्रदर्शित करते हैं। कालानुक्रमिकीय सांख्यिकी वृक्ष जलवायुविक अध्ययनों में प्रजातियों के महत्त्व का संकेत करती है। सहसम्बन्धन तथा अनुक्रिया फलन विश्लेषण के आधार पर ज्ञात वृक्ष वृद्धि-जलवायु के सम्बन्ध मानसूनी महीनों के दौरान वर्षण के महत्त्व को प्रदर्शित करते हैं।

संकेत शब्द—टीक, *टेक्टोना ग्राण्डिस*, वृक्ष वलय, थाईलैण्ड.

INTRODUCTION

THE purpose of this study was to investigate the dendroclimatic response of teak (*Tectona grandis*) growing in a largely undisturbed, natural environment in northern Thailand, at the Mae Na Forest Protection Unit (MNFPU), Chiang Dao. Earlier studies (e.g., De Boer, 1951; Murphy & Whetton, 1989; Pant & Borgaonkar, 1983; Jacoby & D'Arrigo, 1990; D'Arrigo *et al.*, 1994; Pumijumnong *et al.*, 1995a, b) clearly demonstrate the usefulness of teak as a proxy source for rainfall variability and broad-scale climate features such as ENSO. This paper reports on a dendroclimatic analysis of teak samples collected as a part of FIELDWEEK 99, a dendrochronology training workshop held in Chiang Mai, Thailand in February, 1999. This programme was co-sponsored by the National Science Foundation (USA) and the PAGES initiative of IGBP. FIELDWEEK 99 was hosted by the Tree Ring Laboratory of Lamont-Doherty Earth Observatory (USA), in conjunction with Chiang Mai University and the Queen Sirikit Botanic Garden in Mae Rim. The purpose of the FIELDWEEK was to provide training in dendrochronological techniques and dendroclimatic analyses to participants from the southeast Asian region. As part of this programme the Mae Na Teak Project was selected by our group to understand the nature of the relationship between radial growth in teak and climate. The results of these analyses, in addition to being a useful learning exercise, also form an important contribution to the growing dendroclimatic database for the region.

TREE RING DATA

Thirty nine core samples were taken from 12 teak trees at the MNFPU, about 80 km north of Chiang Mai, Thailand (Fig. 1). This remnant stand is protected from logging and other major disturbance, and is considered to be growing in a largely natural environment. Nine of the trees were sampled from four directions (primarily along the four cardinal directions where possible) to reduce the effects of within-tree variability that can be quite large in teak (Pumijumnong *et al.*, 1995a). An additional three trees were cored once only, bringing the total number of cores to 39. All cores were glued to wooden core mounts and surfaced with sand paper up to 400 grit, in order to render the tree ring boundaries more clearly visible. Skeleton plots (Stokes & Smiley, 1968) were used in conjunction with visual inspection to facilitate the correct dating of each sample. While none of the samples is more than 100 years old, good crossmatching has been observed both within and between individual trees. Ring width measurement of all 39 cores was carried out by one of the authors (NP) at Mahidol University, Thailand, and a dating quality control check was initiated with the computer program COFECHA (Holmes *et al.*, 1986).

CLIMATIC DATA

Monthly mean temperature and precipitation data from Chiang Mai, about 80 km south of MNFPU, were used for dendroclimatic analysis. Monthly temperature data are available for the period 1951-90 (40 years), whereas monthly rainfall data cover the period 1911-1997 (87 years). Fig. 2 illustrates the monthly variations in temperature and rainfall based on monthly averages of the available periods. The dry period from December to March receives only 5% of the annual precipitation, while 88% falls during May to October monsoon rains. Mean temperature remains above 20°C throughout the year, with April and May being the warmest months.

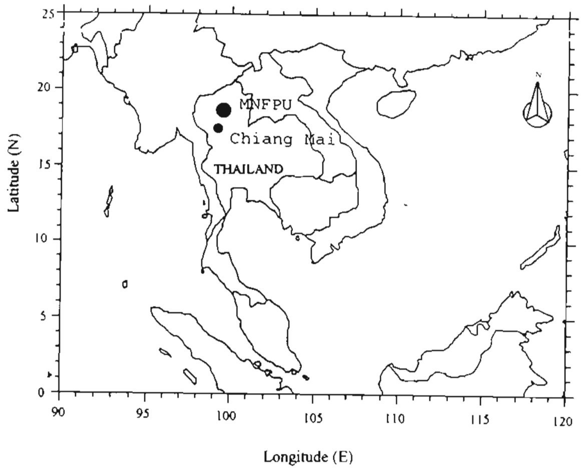

Fig. 1—Location of Mae Na Forest Protection Unit (MNFPU) in northern Thailand.

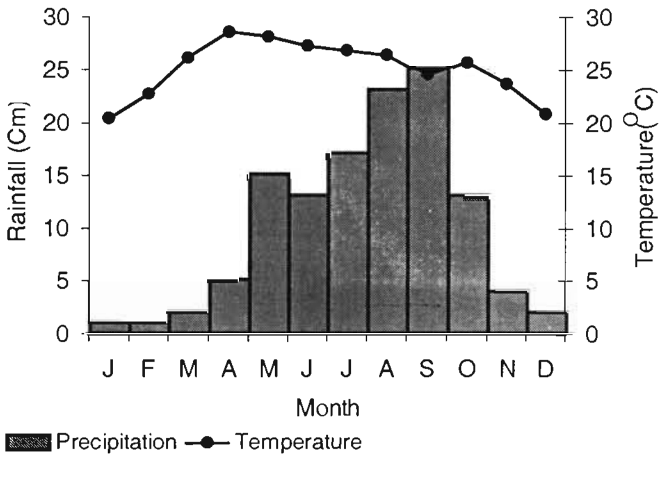

Fig. 2—Monthly variations in temperature and precipitation of Chiang Mai, Thailand based on long-term averages.

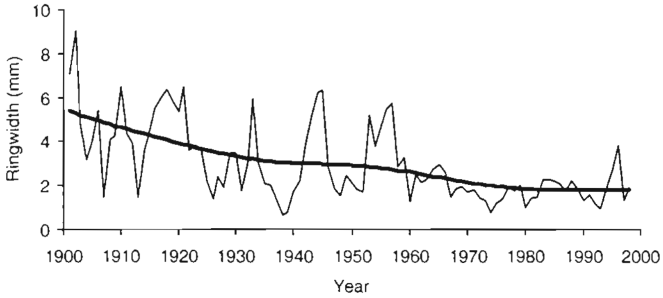

Fig. 3—Teak ring width series at Mae Na along with cubic spline smoothing at a cutoff frequency of 47%N, where N is number of data points.

Sr. No.	Parameter	Standard chronology	Residual chronology
Full chronology period 1901-1998 (98 years)			
1	No. of tree series	12	12
2	Standard deviation	0·26	0·25
3	Mean sensitivity	0·25	0·31
4	Auto-correlation	0·40	-0·05
Common period of the chronology 1924-1995 (72 years)			
5	No. of tree series	12	12
6	Variance (Y%)	28	35
7	Signal to noise ratio	4·6	6·3
8	Variance in 1st eigenvector	34%	41%

Fig. 4—Descriptive statistics of tree ring index chronology of teak at Mae Na, Thailand.

CHRONOLOGY DEVELOPMENT

The oldest teak tree in our study collection spans the 98 years from 1901-1998. Many of our samples exhibit significant persistence (lag-1 autocorrelation) and high values of mean sensitivity, a statistical measure of the degree of change between one value and the next (Fritts, 1976). The sampling strategy of extracting four cores per tree was employed to account for changes in circuit uniformity that are common in teak (Pumijumnong *et al.*, 1995a), and can render any given radius unrepresentative of the overall growth of the tree itself. Circuit uniformity for trees growing at this site was not highly problematic, as within-tree correlations were high between all four directions. However, the temporal length of cores are often different due to obliquity in ring patterns along each radius, likely due to eccentricities in circuit uniformity that caused the core operators to miss the center of the tree. To account for any problems related to the within-tree variability, we averaged all four ring width series from each tree, thereby forming a single series to represent an individual tree. This procedure resulted in 9 averaged series from 9 trees, and 3 series of single cores from the remaining 3 trees. The individual series were then standardised into dimensionless indices in an attempt to optimize the common signal between all trees at the site (Fritts, 1976; Cook *et al.*, 1990).

For standardising ring-width time series we used the computer program ARSTAN (Holmes *et al.*, 1986). Autoregressive modelling was applied to remove the persistence in the series. A cubic spline smoothing (Cook & Peters, 1981) with 47% N years as cutoff frequency (where N is the length of the series) was found to be most suitable for detrending these series. Fig. 3 represents the nature of the ring width series of teak with the cubic spline filter. The ring width index series, derived as the quotient of raw ring width values and the corresponding smoothed values, gives moderately high values of mean sensitivity and common variance explained by the tree assemblage. Good dendroclimatic series are widely considered to have large values of mean sensitivity, large common variance, and low values of lag-1 auto-correlation (persistence) (Fritts, 1976). Fig. 4 gives some key statistics of the standard (with persistence) and residual (without persistence) index chronologies (shown in Fig. 5). In the residual chronology, values for mean sensitivity (0·31) and common variance (35%) have been improved over the standard chronology.

TREE GROWTH-CLIMATE RELATIONSHIP

The simplest method for studying the association between tree growth and climate is through correlation analysis. In the case of teak in Thailand, particularly in northern Thailand, the active growth season is thought to commence some time in April with the onset of rainy season, and end in October when rains cease (Pumijumnong *et al.*, 1995b). Precipitation during these wet-season months largely controls tree growth, however Buckley *et al.* (2001) demonstrated a continued response to rainfall event during the dormant (dry) season that begs further investigation.

The highest rainfall is from June to August, with rains decreasing by October. In contrast, November to March is a mostly dry period with little or no rainfall. Monthly variations of temperature are very small throughout the year, particularly in the rainy season (May-October) when changes in monthly mean temperature are negligible. Therefore, temperature would not appear to exert any obvious limiting control over the radial growth of teak. However, it should be noted that Pumijumnong and Park (2001) note the influence of temperature on the development of earlywood vessels, though have yet to determine whether this is related to an intercorrelation between temperature and precipitation or is truly a response to temperature.

In modelling the tree growth-climate relationship we used monthly climatic data (temperature and rainfall) from Chiang Mai with a dendroclimatic window spanning from the previous October (ending of prior growth season) to the current October (ending of current growth season). In all instances we used the residual (pre-whitened) chronology for

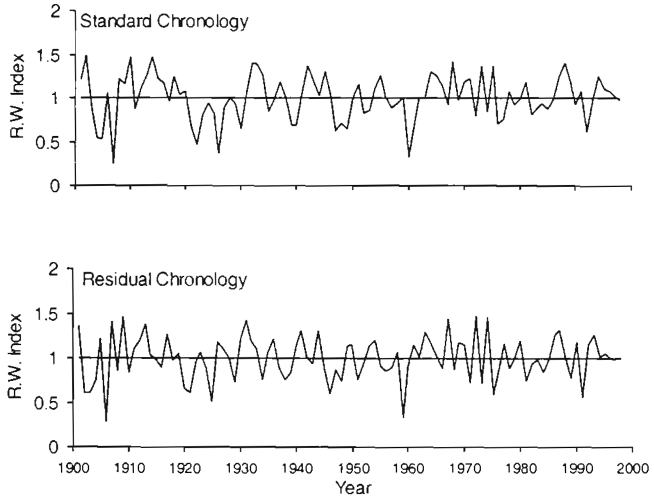

Fig. 5—Teak ring width index chronology at Mae Na representing Standard (with persistence) and Residual (without persistence) versions.

comparison. Fig. 6 shows the correlation coefficients between the residual chronology indices and precipitation and temperature for each month. Previous November and current August precipitation have significant (p<0·05) positive relationships with tree growth. Previous October-November-December (OND) and current July-August (JA) precipitation also have significant (p<0·05) positive correlations with tree growth. None of the temperature parameters indicate significant relationships with the tree-ring chronology.

Another method of studying the dendroclimatic relationship is through response function analysis (Fritts, 1976). This can be a more precise method and gives a quantitative distribution of the response of each climatic parameter independently on tree growth. Response function analysis involves a step-wise multiple regression analysis in which monthly climatic parameters are the predictors and ring widths are the predictand variables. Monthly climatic parameters are generally inter-correlated, so they are first transformed into principle components before entering into the regression equation. Coefficients of the regression equation represent the variance, or the amount of tree growth related to the effect of a particular climate parameter. The use of traditional response function analysis, however, is considered controversial by some researchers (Blasing *et al.*, 1984) due to the subjective nature of screening predictor variables before entering into regression. The possibility for over-inflation of the significance of some parameters is a concern and should be noted.

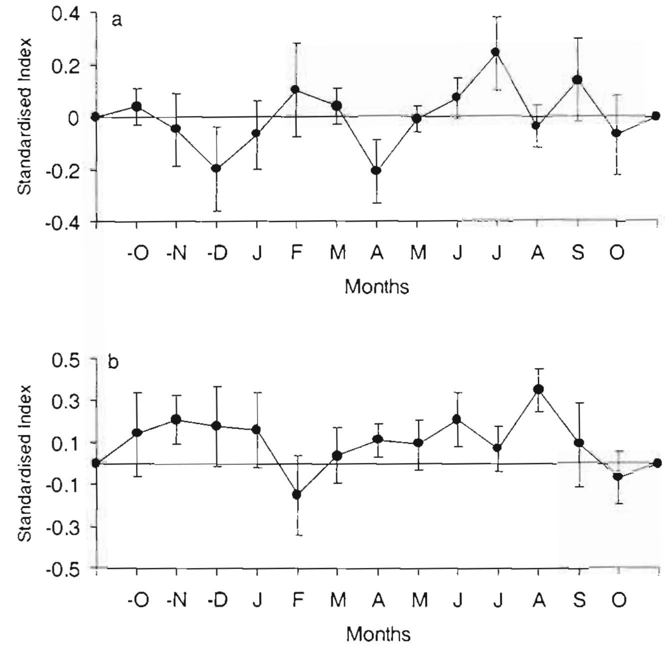

Fig. 7—Response functions using residual ring width index chronology of teak at Mae Na and Chiang Mai temperature (a) and precipitation (b). Vertical bars indicate 95% confidence interval.

Fig. 7 represents the results of a response function analysis with a total of 26 variables; 13 each of monthly mean temperature and monthly rainfall from previous October to current October. Each parameter represents its response on tree growth in terms of the amount of variance in the tree-ring index chronology. Previous November and the current rainy season months of April, June and August indicate significant positive relationships with tree growth. Previous December and current April temperature are negatively associated, whereas, June temperature shows positive response.

DISCUSSION AND CONCLUSIONS

The analyses clearly indicate the important role of precipitation in tree growth activity during the monsoon months, as would be expected, and as is noted in previous work with teak. Precipitation in November of the prior season also appears to be an important parameter, with a significant positive relationship (r=0·4). These results make biological and physiological sense, because an increase in soil moisture at the beginning of the dry season (December-March) and the

Month	-O	-N	-D	J	F	M	A	M	J	J	A	S	O	-OND	JA
Temp.	·01	00	-·10	·05	·15	·09	-·03	-·02	·04	·09	·11	·18	13	-·06	·08
Ppt.	·12	**·40**	·09	·02	-·06	·20	·08	-·05	·18	·14	**·33**	-·14	-·06	**·31**	**·34**

Fig. 6—Correlation coefficients between the residual tree ring chronology and monthly climate (bold figures indicate significant relationship at p < ·05).

carryover effects on the physiological processes of the tree (Fritts, 1976) can both contribute to tree growth. The significant negative relationship with temperature in April (the hottest month of the year) is likely due to moisture stress conditions resulting from high temperature and low precipitation for this month (Fig. 2). Cambial activities in teak are thought to restart during the month of April, though dendrometer band studies presented by Buckley *et al.* (2001) suggest an even earlier start, perhaps as early as February. Higher temperatures will accelerate evapotranspiration causing a lack of moisture during the very early period of growing season when cambial cell division is most rapid. This would create unfavourable conditions for tree growth, and may be responsible for the negative relationship of April temperature with tree growth. Conversely, higher than average precipitation in April is conducive to increased growth.

During the wet season (May to October) temperature does not appear to play any direct role in radial tree growth. Precipitation shows positive response with tree growth during these months, as might be expected. Drought conditions coincide with below average radial growth, hence teak can be very useful for the reconstruction of drought events in the past, and more broad-scale climate features related to variations in monsoon rainfall such as ENSO (D'Arrigo *et al.*, 1994).

The results from this study are based on the chronology from a single stand of teak with limited sample size and temporal coverage. However we derive similar results to the investigations by Pumijumnong *et al.* (1995a, b), carried out over a broad area of northern Thailand.

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