

Original article

**Climatic Signals Derived from the Growth Variation and Cycles of
Pinus merkusii in Easternmost Thailand**

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ABSTRACT

Pinus merkusii is a tropical tree species that has been proven suitable for dendroclimatic studies. In the last 10 years, most of the tree-ring research on *P. merkusii* has focused on the northern region of Thailand. Our study site was a pine stand located on a rock cliff in the easternmost region of Thailand (latitude 15° 31' N and longitude 105° 37' E). In early 2009, 66 cores from 30 *P. merkusii* trees were collected and prepared following standard dendrochronological methodology. A tree-ring chronology was constructed covering the period 1881–2008, with excellent crossdating properties over most of that interval. Based on this tree-ring chronology, most notable below-average growth was during the 1960s to the 1990s. Except for the growth before this interval and the last decade in this period, growth variations were close to the average. The last decade of data showed an increasing growth trend above the average. Spectral analysis indicated the cycle of growth variability of *P. merkusii* in easternmost Thailand was 3.8–4.7 years. An analysis of the local climatic signals on tree-ring chronology indicated a strong relationship between pine growth and the current year's rainfall at the beginning of the wet season and with the previous year's temperature during the transitional period of the wet and dry season. An analysis of regional climatic signals indicated that the tree-ring index was correlated with the Equatorial Southern Oscillation Index (SOI) and the Tropical Pacific Sea Surface Temperature (SST). The results indicated a positive response to SOI in September of the previous year, and indicated a negative response to SST in August of the previous year. From this study, we can conclude that the long term variation of both local and regional climatic signals can be determined using the radial growth of *P. merkusii* in easternmost Thailand.

Keywords: *Pinus merkusii*, Merkus pine, Tropical Pacific SST, Equatorial SOI, Dendroclimatology, Tree-ring chronology, Thailand, Spectral analysis

INTRODUCTION

Tree-ring studies (dendrochronology) have been successfully applied for palaeoclimatic reconstruction and predicting trends in climatic variability, especially in the temperate zone. In the tropics, tree-ring analysis of the role of tropical climate on the fluctuation of the global climate system has also been rapidly increasing over the past decade (Buckley *et al.*, 1995, 2005, 2007a, 2007b; D'Arrigo *et al.*, 1994, 1997, 2006; Heinrich and Banks, 2006; Pumijumnong *et al.*, 1995; Pumijumnong and Wanyaphet, 2006; Sano *et al.*, 2008; Therrell *et al.*, 2006). However, it is still difficult to find suitable tree species whose growth sensitivity to climate can be proven using annual rings.

In Thailand, *P. merkusii* or merkus pine has been widely used for dendroclimatic research (Buckley *et al.*, 1995, 2007a; D'Arrigo *et al.*, 1997; Pumijumnong and Wanyaphet, 2006). Previous researchers of merkus pine mostly presented a climate-growth relationship during the monsoon period, but the major climatic factor inducing growth was not the same; Buckley *et al.* (1995) and D'Arrigo *et al.* (1997) found a temperature-growth response of merkus pines located in lower northern Thailand, while Pumijumnong and Wanyaphet (2006) discovered a growth response of merkus pines to rainfall in upper northern Thailand. Additionally, studies of merkus pines from Lao Peoples Democratic Republic (PDR) presented a correlation with the previous year's monsoon rainfall (Buckley *et al.*, 2007a). Our study focused on the investigation and explanation of local and regional climatic

signals derived from the growth of *P. merkusii* located in easternmost Thailand.

MATERIALS AND METHODS

Study Site

The study site for *P. merkusii* was located at Pha-Chana Dai, Khong-Jiam district, Ubon Ratchathani province, at latitude 15° 37' N and longitude 105° 37' E (Figure 1). Here, the mostly stunted merkus pines were growing on a rock cliff near the border with Lao PDR and Cambodia, in association with other dry dipterocarp forest tree species, such as *Shorea obtusa*, *S. siamensis* and *Dipterocarpus obtusifolius*.

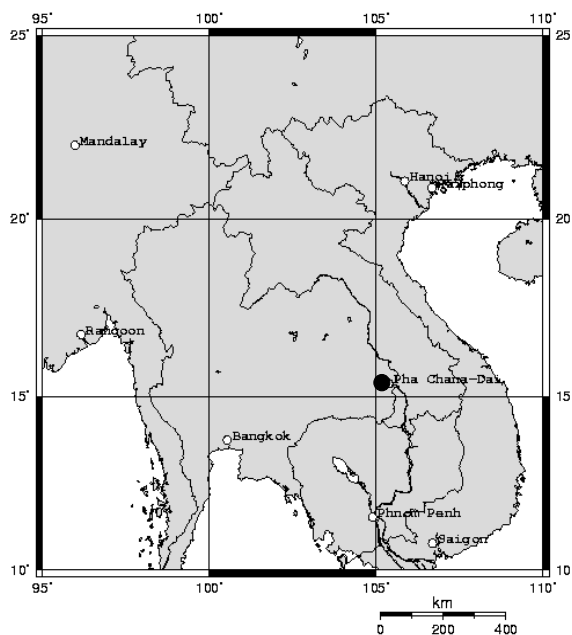


Figure 1 Map of *P. merkusii* study site (black circle) in easternmost Thailand, close to the Lao PDR and Cambodian borders.

Meteorological Data

To explore the correlation between local climate variation and merkus pine growth, climatic data from two meteorological stations were used. The nearest meteorological station to our study site, the Khong-Jiam meteorological station, recorded only rainfall data with no temperature data. The 32-year average monthly rainfall (1976-2007) indicated that the monsoon rainfall ranged from May to September (Figure 2a). The fitted straight line showed an increasing trend of annual rainfall, except during the extreme drought period in 1982–1983 (Figure 2b). This extreme drought might have been related to the strong El Nino drought years of 1982 and

1983. The Ubon Ratchathani meteorological station, which is further from the study site, was selected as the source of temperature and relative humidity data as well as longer rainfall records. The monthly temperature data showed the highest values in the pre-monsoon period and lowest values during and after the monsoon period. The Ubon Ratchathani rainfall data showed the highest values at the end of the monsoon period (Figure 3a), a pattern similar to that of the Khong-Jiam rainfall data. In Ubon Ratchathani, from 1951 to the present time, the temperature clearly showed an increasing trend (Figure 3b), while the total annual rainfall showed some rising trends.

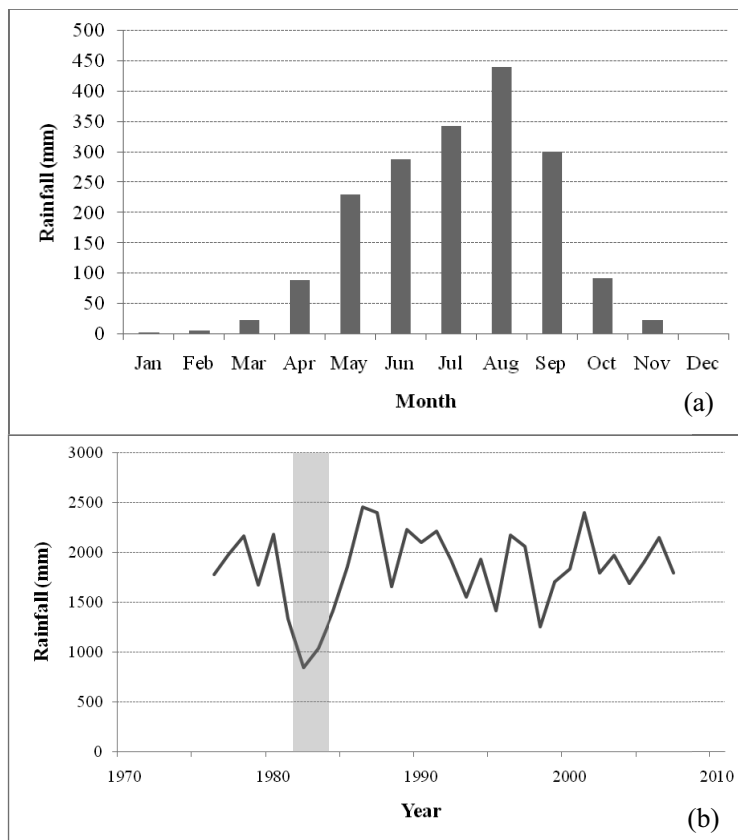


Figure 2 Monthly and annual rainfall from the Khong-Jiam Meteorological Station: (a) average monthly rainfall from 1976 to 2007, (b) total rainfall from 1976 to 2007; the vertical grey band shows the extreme drought years in 1982 and 1983.

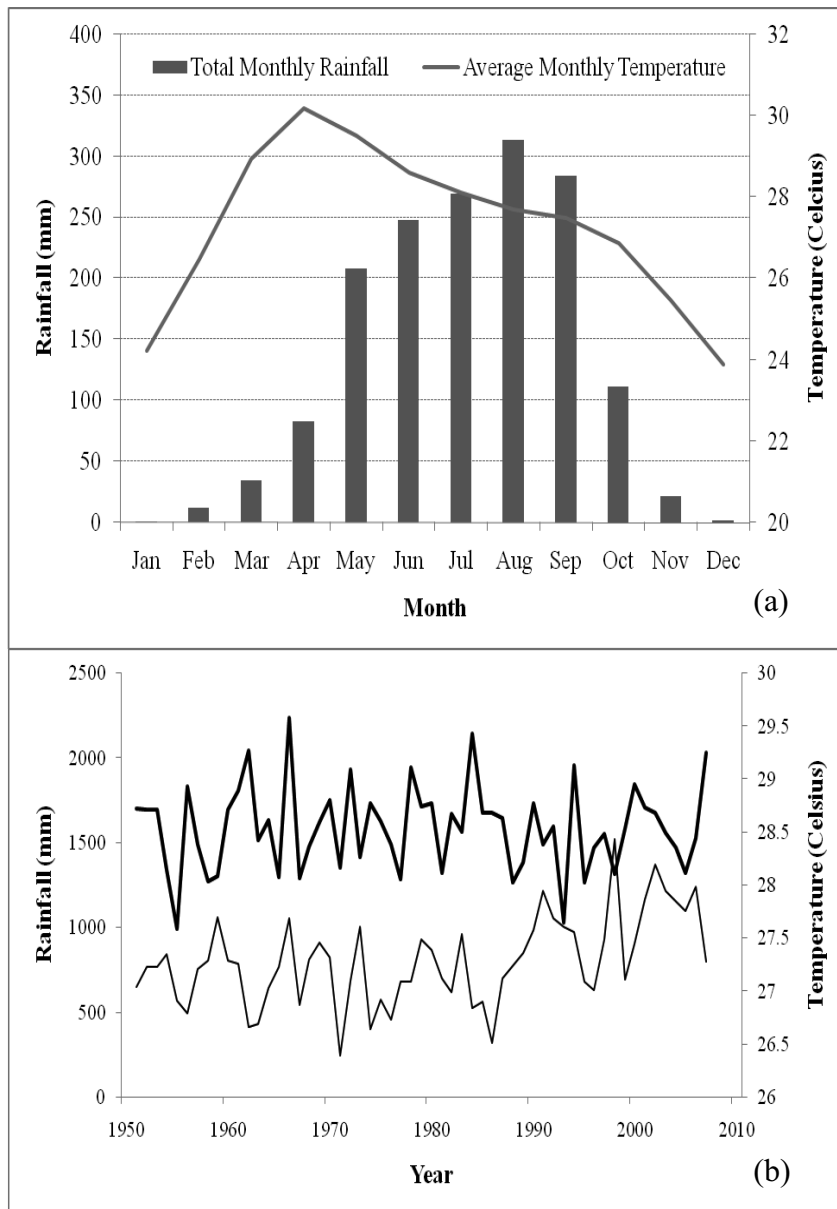


Figure 3 Rainfall and temperature data from Ubon Ratchathani Meteorological Station: (a) average monthly rainfall and temperature (1951-2007), (b) total rainfall (thick line) and average temperature (thin line).

Sample Collection and Preparation

In early 2009, 66 sample cores from 30 mature merkus pine trees were obtained using an increment borer at above ground level, with at least two cores per tree. The trees were subjectively selected based on the criteria of dominance and crown symmetry. Following the standard dendrochronological methods (Stokes and Smiley, 1968), at the Laboratory of Tropical Dendrochronology (LTD), all sample cores were glued and fixed onto wooden supports with the transverse axis exposed. The core samples were air dried at room temperature followed by surface preparation that involved progressively smoothing the surfaces with sandpaper until the boundary of each annual ring was more clearly visible.

Ring Width Measurement and Tree-Ring Index Construction

All cores were visually cross-matched to specify the calendar year of every growth ring and to classify which tree-rings were annual rings, false rings, or missing rings. The ring widths of all cross-matching annual rings were measured using a 0.001 mm accuracy sliding stage micrometer linked directly to a computer to record the measurements. Dating quality was re-checked using the computer software COFECHA (Holmes, 1983). Later, the individual measured ring width series were standardized to obtain the tree ring or chronology index using the updated version of the ARSTAN program (Cook, 1985). The standardization removed the aging effect. Each ring width series was detrended using a

negative exponential curve or a straight line of negative slope. Several series, which could not be fitted with these models, were fitted with the Hegershoff growth curve. Finally, all series were averaged for each year to obtain a master chronology (or tree ring) index using the bi-weight robust mean function.

The chronological signal strength was evaluated based on an acceptable number of the population and a measure of the average correlation between ring-width series, using the calculation of the running R_{bar} and the Expressed Population Signal (EPS), with an acceptable EPS of 0.85 or higher (Wigley *et al.*, 1984; Cook and Kairiukstis, 1990). The power spectra (Schulz and Mudelsee, 2002) from the merkus pine index were then analyzed to examine the rhythm or the cyclic signature of tree growth with the aim of supporting the variability of the climatic signal on tree growth.

Climate-Growth Relationships

The local climatic data average monthly temperature, total monthly rainfall, and average monthly relative humidity were correlated with the ring-ring index by using simple linear correlation and regression. In addition, the 59 year data set of the Equatorial Southern Oscillation Index (Equatorial SOI), available via <http://www.cpc.ncep.noaa.gov/data/indices/reqsoi.for>, and the Sea Surface Temperature (SST) over the tropical Pacific Ocean from 1948-2007, available via <http://www.esrl.noaa.gov/psd/data/correlation/eofpac.data>, were correlated with the tree-ring index to indicate the regional climatic signals.

RESULTS AND DISCUSSION

Tree-Ring Data and Chronological Index

Out of the 66 core samples of *P. merkusii*, we were able to crossdate 63 cores; the rest were rejected due to broken samples on which it was difficult to measure the ring width. The mean series intercorrelation, mean sensitivity, and mean length of the series were 0.572, 0.385, and 88.3, respectively. Plots of the mean ring width, tree-ring index, sample sizes, R_{bar} , and EPS are shown in Figure 4. With the crossdated ring width data of *P. merkusii*, we were able to construct the chronological index covering the past 128 years from 1881 to 2008 (Figure 4b). Using the calculated Express Population Signal (EPS), the sufficient sample sizes shown in Figure 4c including excellent crossdating indicated an acceptable EPS for the overall *P. merkusii* chronology (Figure 4d).

Based on tree-ring chronology, a 10-year moving average was calculated to demonstrate the growth decline below the average from the 1960s to the 1990s (Figure 5a). The chronology was split into two segments (1881–1959 and 1960–2008), and straight lines were fitted to these data sets to illustrate the change in growth trends (figure 5b). The tree-ring index from the early 1880s to the 1950s showed a gentle decline of tree growth, with the variation still close to the average growth. The tree ring index from the last chronological segment (1960s–2000s) showed increasing growth rates and close to the average growth at the end of the last decade.

The power spectra of the merkus pine index (Figure 6) which were derived from

the REDFIT spectral analysis illustrated the significance ($p < 0.05$) of growth cycle and variability with a strong peak around 3.8–4.7 years as similar as the variability of ENSO (Solomon *et al.*, 2007) This merkus pine index also illustrated growth variation resembling other Thai teak indices (Buckley *et al.*, 2007b; Pumijumnong, 2012) and the Lao merkus pine index (Buckley *et al.*, 2007a) which reflected the influence of regional climate on tree growth in this region.

Climatic Signals

The climate-growth relationships were analyzed at the local climatic and regional climatic levels. For the local climatic signals, the chronological index was compared with several climatic data sets over 32 years, including the Khong-Jiam monthly rainfall (1976–2007) and the Ubon Ratchathani monthly rainfall, temperature and relative humidity from 1951–2007. The chronology index was correlated with individual climatic factors in both the current year (t) and the previous year ($t-1$). For the current year climate-growth correlation, the growth of easternmost Thai merkus pines was significantly ($p < 0.01$) and positively correlated with the Khong-Jiam rainfall in May (Figure 7a). The previous year's temperature in December and relative humidity in May were negatively and positively correlated with tree growth in the current year, respectively (Figures 7c and 7e). There was no significant correlation between merkus pine growth and the total monthly rainfall derived from the Ubon Ratchathani station.

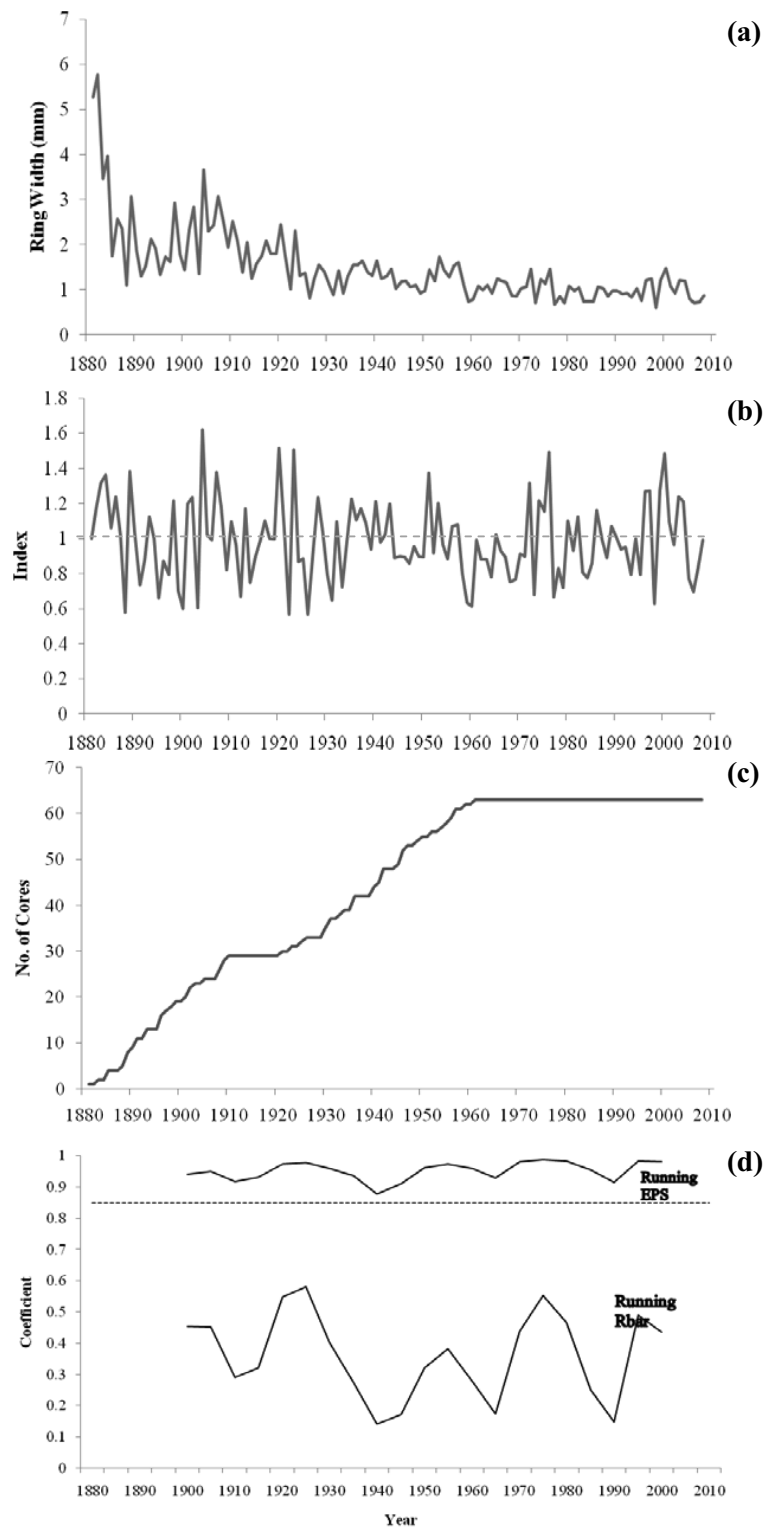


Figure 4 *P. merkusii* annual ring plots: (a) mean ring width; (b) standardized ring width (chronological index); (c) sample size, and (d) running EPS and Rbar

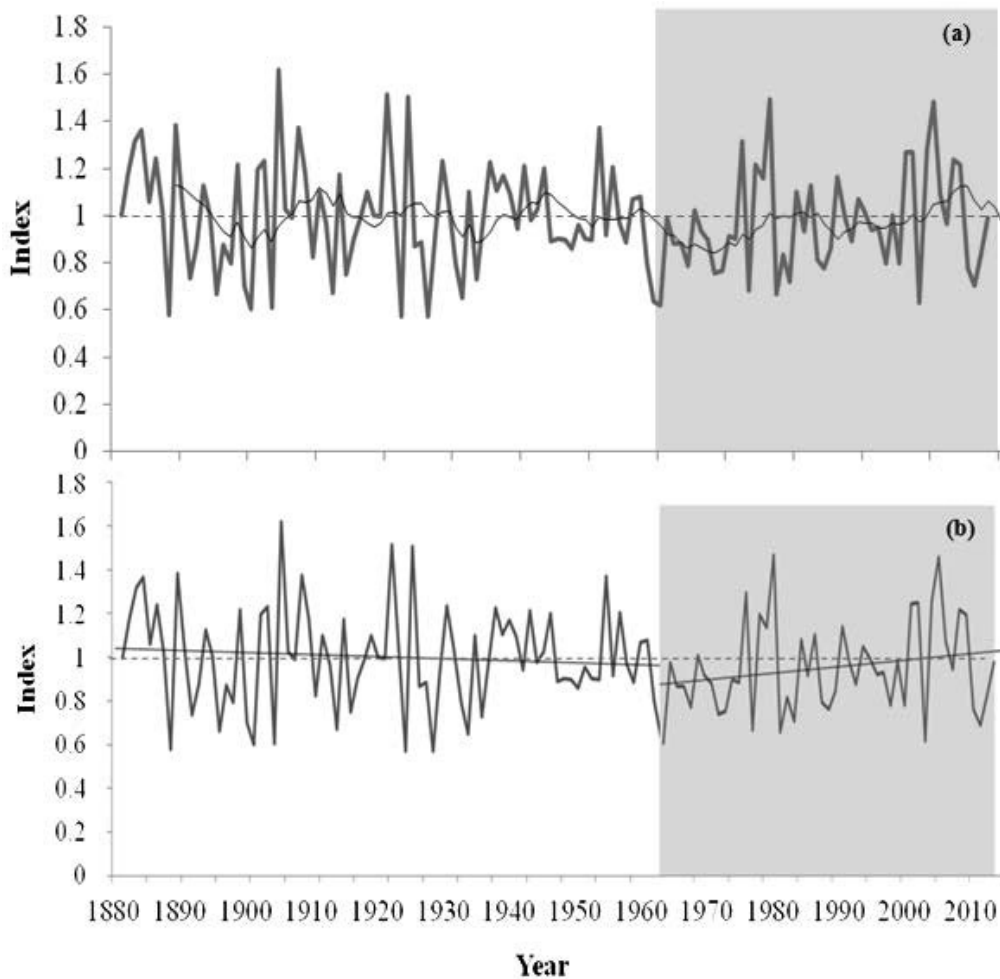


Figure 5 *P. merkusii* chronology: (a) chronological index (thick line) and 10 year moving average (thin line), the gray band was split into two chronological segments; (b) chronological (thick line) and linear growth trend (thin line) of two chronological segments. Dashed lines in a) and b) indicate the average growth

The ring width variation explained by the current year's data for Khong-Jiam's May rainfall was 28.4% ($n = 31$) (Figure 7b). The previous December's temperature and previous May's relative humidity explained 13.2% ($n = 56$) and 16.8% ($n = 56$) tree growth variation in the current year, respectively (Figures 7d and 7f). We can postulate that the increasing rainfall in May, the beginning of

the growing season, stimulated tree growth, while the low temperature at the end of previous year induced almost complete cessation of growth in that year and accumulated the remaining food for the next growing season. These results are similar to those of Pumijumnong *et al.* (2006) and Buckley *et al.* (1995, 2007a).

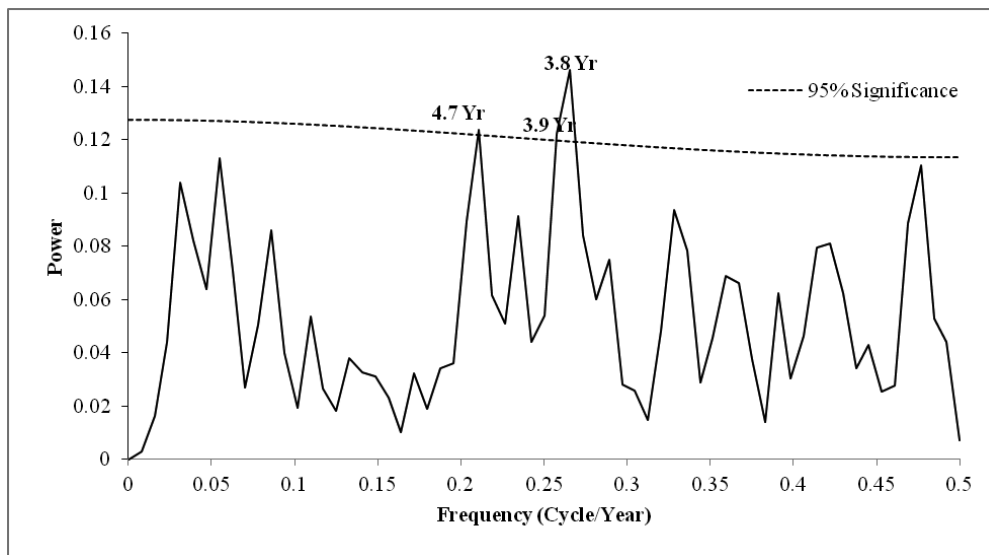


Figure 6 REDFIT power spectra of the merkus index. Peaks above the dashed line indicate significance at the 95% level.

Pumijumnong *et al.* (2006) suggested that the growth of *P. merkusii* in northern Thailand positively depended on rainfall at the beginning of the wet season, which was similar to this study, while Buckley *et al.* (1995, 2007a) showed a significant positive relationship between the growing season temperature and the growth of *P. merkusii* in northern Thailand and northeast of Vientiane, Lao PDR.

Due to the variation in the sample sizes of the climate-growth analysis, it was difficult to decide which local climatic factors mostly induced tree growth. Therefore, the sample sizes of all climatic data were fixed for the common period of 31 years ($n = 31$) from 1977 to 2007 and the climate-growth relationships were re-analyzed. The previous year's temperature from the transitional period of the wet and dry season still

demonstrated the growth inducement. However, the relationship changed from a negative correlation in December as indicated in the prior study to a positive correlation in August. The August temperature explained about 30% of the growth variation (Figure 8). In moist areas at the study site, the increase in temperature at the end of the growing season might extend the length of the growing period and the accumulation of food, which in turn will increase the potential for rapid cambial growth in the next growing season.

The analysis of regional climatic signals indicated that the regional climatic variations could also be explained using the growth of merkus pines. The Equatorial SOI and Tropical Pacific SST monthly data from 1950 to 2008 were correlated with the tree-ring index. The Equatorial SOI and Tropical Pacific

SST during the monsoon and post-monsoon periods of the previous year were significantly correlated with the tree-ring index. The September SOI and June SST in the previous year significantly ($p < 0.01$) affected the tree-ring

width index of the current year. The SOI and SST were positively and negatively correlated with the growth index and explained 24% and 26% of the growth of merkus pines, respectively (Figure 9).

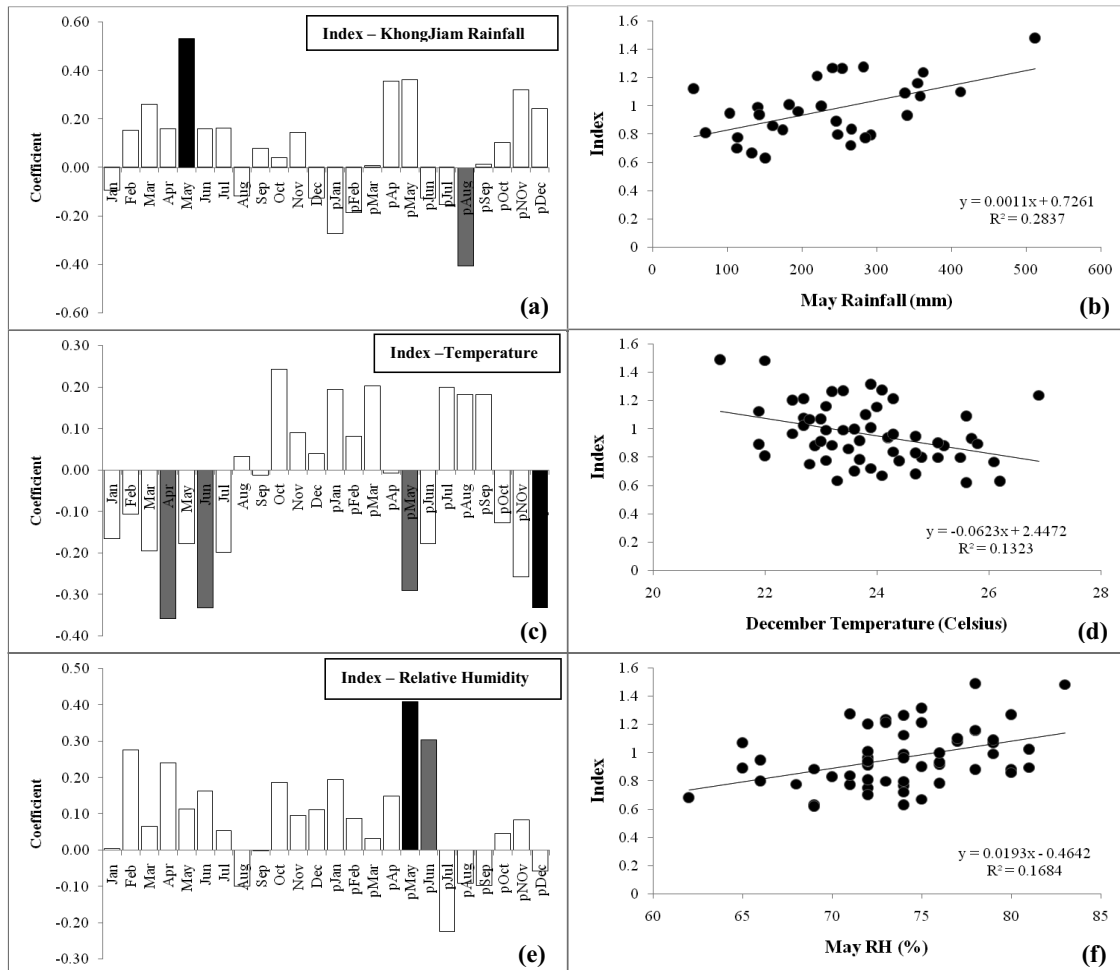


Figure 7 Correlation plots between local climatic data and *P. merkusii* ring width chronology: (a) Rainfall-growth correlation; (b) May rainfall-growth correlation; (c) Temperature-growth correlation; (d) December temperature-growth correlation; (e) Relative humidity-growth correlation; (f) May relative humidity-growth correlation. The gray and black columns represent significant correlation, while black columns represent the greatest significant correlation.

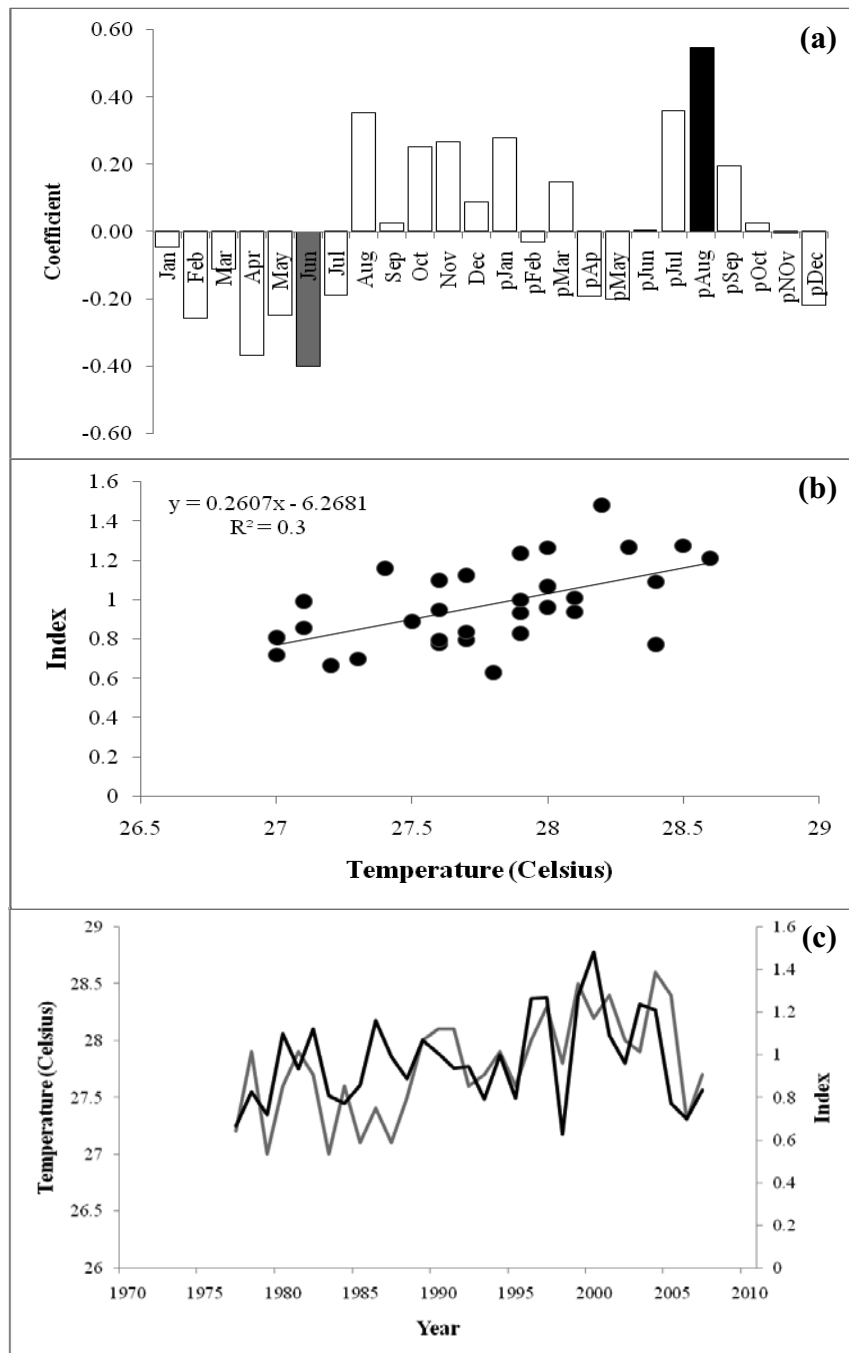


Figure 8 *P. merkusii* growth and August temperature in previous year correlation from 1977 to 2007: (a) gray and black columns represent significant correlation, while black columns represent the greatest significant correlation; (b) linear regression of pine growth and August temperature in previous year; (c) trend of pine growth compared with August temperature in previous year, black and gray lines indicate pine growth and temperature, respectively.

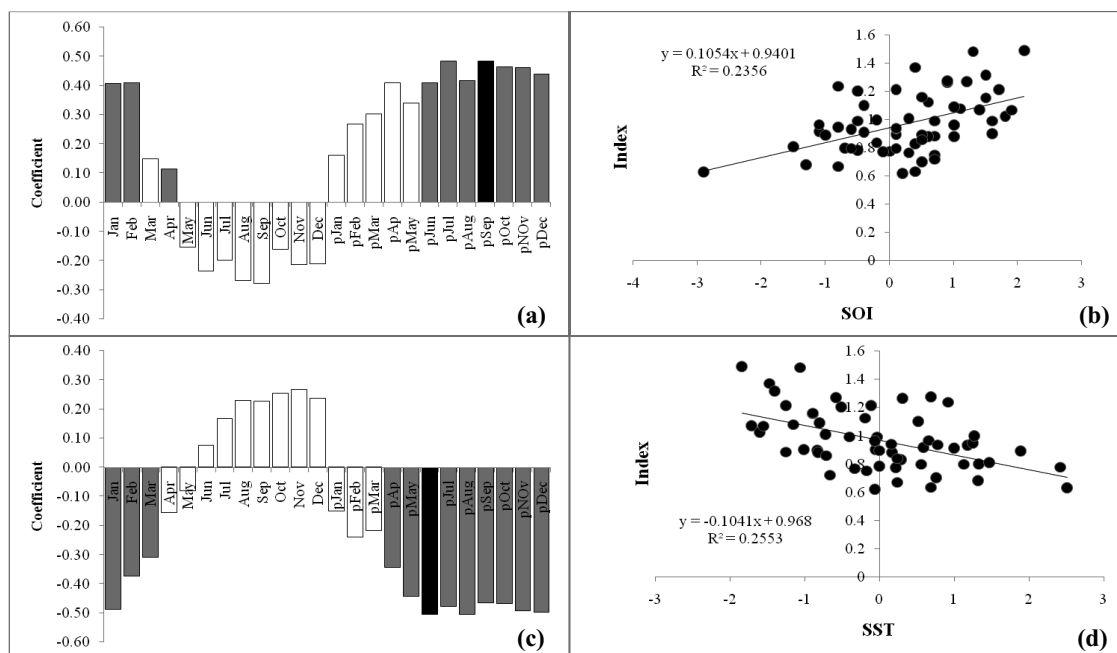


Figure 9 Correlation plots between regional climate and *P. merkusii* ring width chronology: (a) and (b) indicate SOI-growth relationship; (c) and (d) indicate SST-growth relationship. Gray and black columns represent significant correlation, while black columns represent the greatest significant correlation.

The average annual SOI explained 25% of the growth of the merkus pines, as did the SST in June. However, the signal derived from the average annual SOI might be more useful than the one month SST since the SOI changes could be used to indicate ring width index variation over the whole year. The pine growth and average annual SOI relationship is shown in Figure 10a. The comparison of actual SOI and the estimated SOI based on the SOI-growth relationship (Figure 10a) is depicted in Figure 10b.

CONCLUSION

The 128 year chronology of *P. merkusii* collected from Pha-Chana Dai National Park, in easternmost Thailand, constructed back to 1881, indicated that the growth increased in the last five decades with the cycle of growth variability being 3.8–4.7 years. This increase in growth corresponded to the increased Khong-Jiam annual rainfall and the Ubon Ratchathani temperature. That is, the chronology index was correlated with local

climate (i.e. rainfall, temperature, and relative humidity). Merkus pine chronology could also be used to explain the dynamics and the changes in the regional climate (equatorial SOI and Tropical Pacific SST). It was found that the changes in the local climate stimulated tree growth in the current year, while the

regional climate in the prior year induced tree growth in the current year. Therefore, we conclude that that signals derived from the radial growth of merkus pine in easternmost Thailand could be used to monitor both local and regional climatic changes.

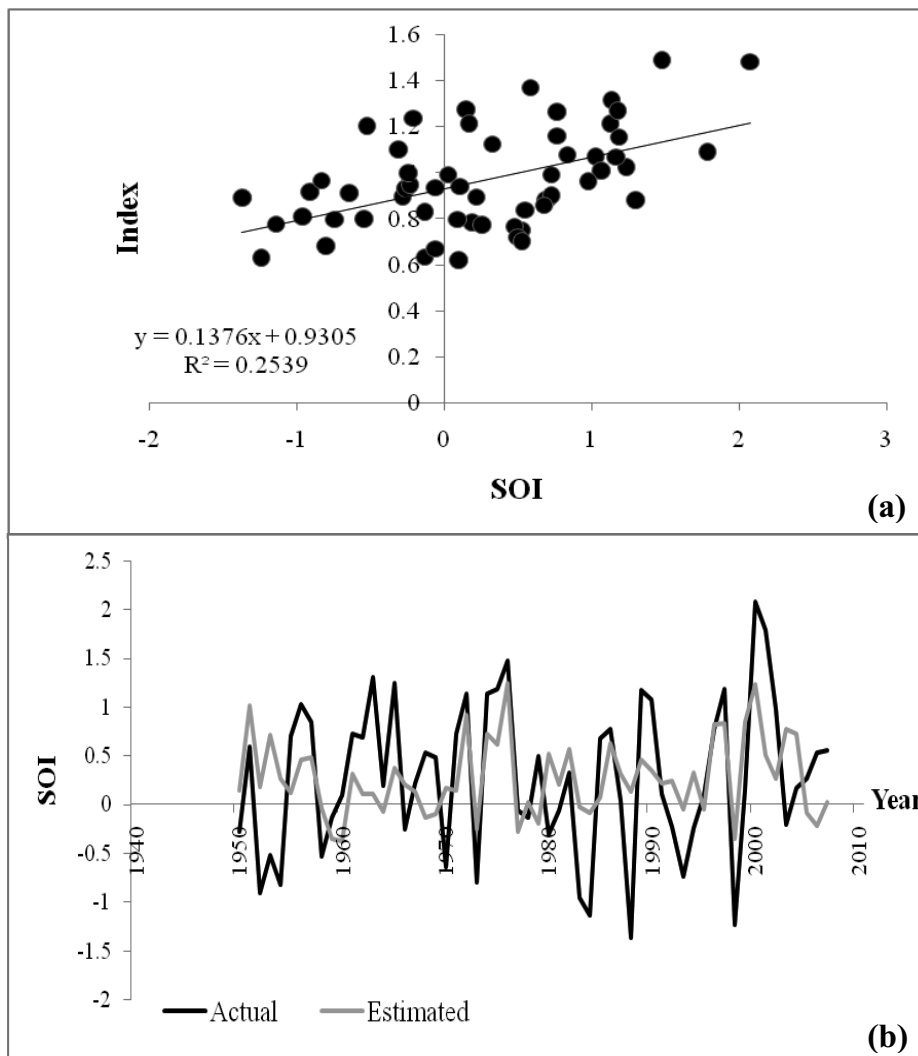


Figure 10 *P. merkusii* growth index and average annual SOI correlation: (a) SOI-growth relationship; (b) estimated-actual SOI comparison

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