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Original article

Pine growth variation and climate change: Opportunities for dendroclimatology in central Thailand

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ABSTRACT

This study investigated the relationships between tree growth and climatic data in *Pinus merkusii* using dendrochronological techniques. The aim was to demonstrate the opportunities for climatic reconstruction in central Thailand. A sample of 48 cores collected from 24 trees was subjectively selected from the Phutoei National Park in Suphan Buri province in central Thailand. A 229-year tree-ring chronology was built from 1779 to 2007 and was correlated with climatic data collected at the Suphan Buri Meteorological Station. The chronology indicated a high positive correlation ($P<0.01$) with the present and previous year average temperature and the current year temperature in October. The annual ring width chronology of merkus pine could be divided into three segments of A.D. 1779-1839, 1840-1992 and 1993-2007 based on their growing patterns. The averages of annual ring width indices in these three segments were 1.13, 0.86 and 1.63 cm, respectively. From 229 years of October temperature data reconstructed from the annual ring width index, the results showed a high fluctuation of temperature with the mean temperature in October being 27.750 °C. The trend of reconstructed temperature in 1779-1839 increased to 27.84 °C and gradually decreased to a stable temperature of 27.68 °C in 1840-1992. In 1993-2007, the temperature rapidly increased to 28.17 °C. In addition, anomalous events occurring in some growing years illustrated increased temperature fluctuations revealing a cycle of 2.5-5, 57, 76 and 114 years, respectively.

Keywords: *Pinus merkusii*, Tree growth, Climate change, Dendroclimatology, Tree-ring analysis

INTRODUCTION

Knowledge of tropical climate change as it affects human activities and natural resources, especially forest resources, is important. However, the recorded climate data are not sufficient to explain climatic dynamics at local scales. Therefore, other techniques need to be applied to study the past climate. Thus, the increasing demand to understand climatic response in the past using tree-ring analysis has encouraged dendroclimatologists to expand their research into the tropical forests, which have a very high diversity of tree species. However, so far only a few suitable tree species have been shown to have annual tree-rings and so have been successfully used for dendrochronological research.

Tree-ring studies have been increasing in Thailand over the past decade. Dendroclimatologists in Thailand have conducted successful studies in teak (*Tectona grandis*) and pine (*Pinus* spp.) (Buckley *et al.*, 1995, 2001, 2007a, 2007b; Pumijumnong *et al*., 1995; Pumijumnong and Wanyaphet, 2006; Duangsathaporn and Palakit, 2013). They discovered that pine and teak ring width variation were related to changes in temperature and rainfall. All these studies were located in the northern and north eastern region. On the other hand, *Pinus merkusii* (two needle pine) has been studied just once in central Thailand in Suphan Buri province about 150 km from Bangkok.

The objective of the current study was to investigate the relationships between tree-growth and climatic data in *Pinus merkusii* growing in the Suphan Buri province in central Thailand. The aim was to demonstrate the opportunities for climatic reconstruction in central Thailand.

MATERIALS AND METHODS

The Study Location

The tree-ring data used for this study were derived from merkus pine *(Pinus merkusii* Jungh. & de Vriese), growing in the Phutoei National Park, situated in Suphan Buri province, about 150 km north of Bangkok (Figure 1). The Suphan Buri province has a large population and it is an important industrial, agricultural, and economic zone of the country. The Phutoei National Park consists of a complex of mountain ranges, with the highest point at 1,123 m above mean sea level. The park area is 317.47 km^2 (about 198,422 rai) and has been a national park since September 30, 1987. The weather in this area is quite hot early in the year and has heavy, continuous rain year round; especially during August to October. The forest in this area is productive forest, consisting of natural pine forest, tropical rainforest, mixed forest and deciduous forest mixed with semi-evergreen forest. Pine forest (*Pinus merkusii*) has medium-sized to large-sized trees, which commonly reach a height of 30-35 m and a diameter of 50-80 cm. The species has a straight and cylindrical trunk, which is very resinous. Its bark is thick, reddish-brown, splitting deeply and longitudinally. The sample site was located at 600 m above mean sea level.

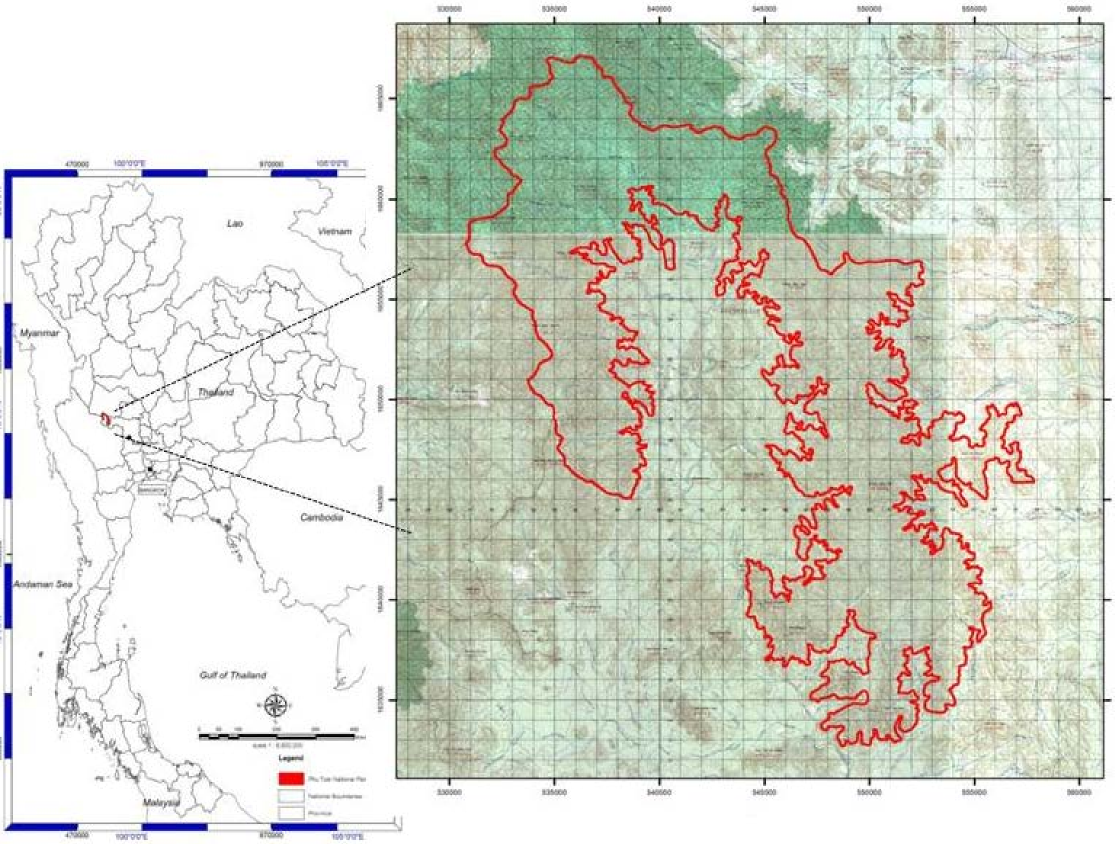

Figure 1 Map showing location of *Pinusmerkusii* study site in central Thailand.

Fieldwork Sample Collection

Forty-eight increment core samples were collected in September 2008, from 24 living pine trees. Two cores were taken from each tree, usually from opposite sides of the stem. Dominant trees were subjectively chosen and trees with obvious bruises, scars, and other effects such as fire and insect disturbance, were avoided. In the Laboratory of Tropical Dendrochronology (LTD), samples were prepared following standard dendrochronological methods (Stokes and Smiley, 1968). All specimens were dried, glued, and mounted onto wooden supports with the cross section position upward. Surface preparation involved progressively fining with 200 and 400 grit sandpaper until the boundary of each annual ring was more clearly visible under the stereomicroscope.

Meteorological Data

Fifty-four years of climatic data (available for the period 1953-2007) consisting of average monthly temperature, total monthly rainfall, and average monthly relative humidity data, were obtained from the Suphan Buri Agromet Meteorological Station in Mueang district, Suphan Buri province (about 60 km from the Phutoei National Park). These data were published by the Thai Meteorological Department. (Figure 2)

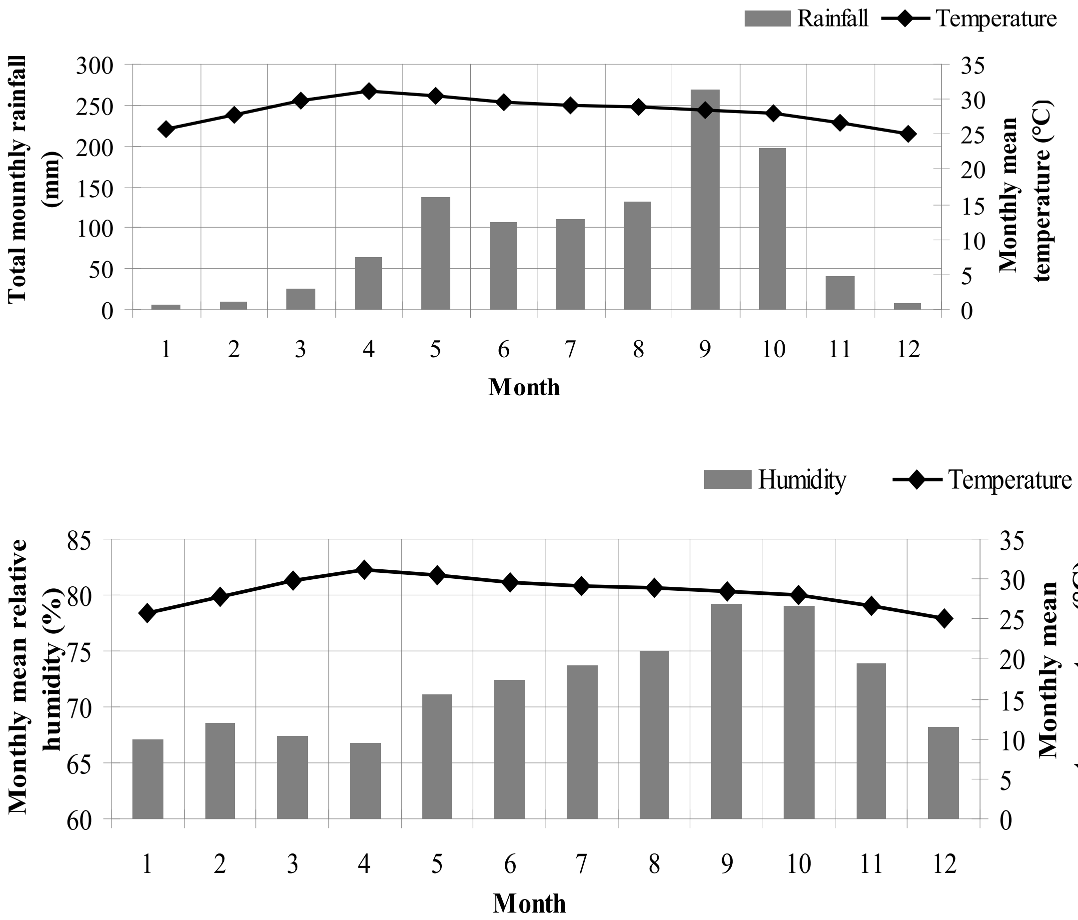

Figure 2 Monthly mean temperature and total monthly rainfall (top) and monthly mean relative humidity(bottom) from 1953 to 2007 at SuphanBuriAgromet Station in Mueangdistrict in SuphanBuriprovince (about 60 km from the study area).

Ring Width Measurement and Tree-Ring Index Construction

All cores were crossdated, and annual rings, false rings, and missing rings were identified. After successful crossdating, total tree ring widths were accurately measured using a 0.001 mm sliding stage micrometer interfaced directly with a microcomputer for recording the measurements. The accuracy of crossdating was subsequently checked using the COFECHA program (Holmes, 1983). A variety of growth functions were used for the curve-fitting of each sample core data. These functions, which indicated the relationships between tree-ring width and year, consisted of the S-curve (sigmoid growth) equation, the negative exponential equation, and the linear equation. Standardized ring-width series, also called ring-width index, were obtained by dividing the ring width by the value predicted by the fitted curve for a particular year (Cook and Peters, 1981, Fritts, 1976). Standardization of ring-width measurements is necessary to remove the decrease in size associated with age; other factors are removed by fitting a curve to each measured series (Fritts, 1976). Finally, all sample core indices were averaged and the ring width index of the site was formed. These procedures were completed using the ARSTAN program (Cook, 1985).

Climate-Growth Response Analysis

The local climatic data consisting of average monthly temperature, total monthly rainfall, and average monthly relative humidity data (Figure 2) were correlated with the ring-width index using simple linear correlation and multiple regressions. The ring-width index was defined as the dependent variable and climatic data were defined as independent variables.

Climate Reconstruction

The climatic variables for the reconstruction were chosen on the basis of the response function. The data were divided into early and last periods in order to assess the temporal model stability of the identified models. Calibration-verification statistics, commonly used in dendroclimatology were calculated to confirm the model reliability (Cook and Kairiukstis, 1990). The statistics were Pearson's correlation coefficient (r), the reduction of error statistic (RE), the product means test (PM), and the sign test (s: number of incorrect signs) (Fritts, 1976; Cook *et al*., 1994). The tests were computed using the verify routine (VFY) of the Dendrochronology Program Library (DPL) software (Holmes, 1994). Spectral analysis (Jenkins and Watts, 1969) was used to evaluate the frequency domain properties of the reconstructed climate using the REDFIT procedure (Schulz and Mudelsee 2002).

RESULTS AND DISCUSSION

Chronology Development

In total, 48 cores from 24 trees were successfully crossdated. The crossdated ring width data could be extended back 229 years. The time range(in years) was 1779-2007 (Figure 3a). The mean series intercorrelation was 0.537, the average mean sensitivity was 0.359, and the mean length of series was 184.7 years.

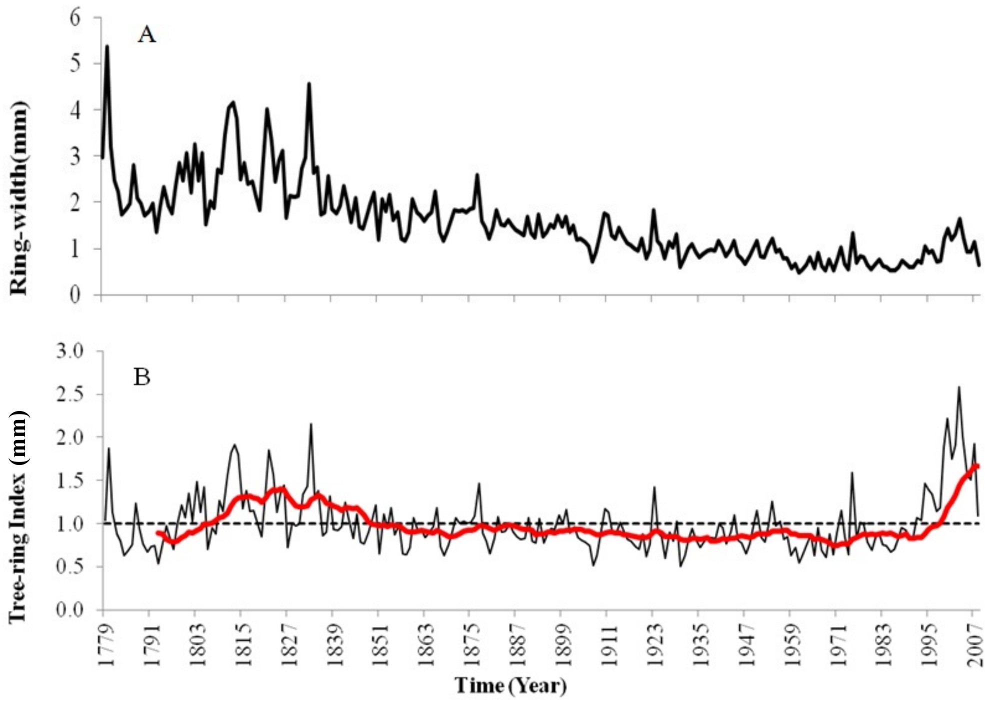

Figure 3 (A) Average ring-width of *Pinusmerkusii* in Phutoei National Park, SuphanBuriprovince, central Thailand. (B) Standardized chronological index and its 15-year moving average.

The growth models fitted to each sample core indicated a significant correlation between tree-ring width and year of 78% for the S-curve equation, 20% for the negative exponential equation, and 10% for the linear equation. Thus, the S-curve equation was identified as adequate for Thailand pines because it appears to approximate well pine growth. The tree-ring indices constructed using ARSTAN (Cook, 1985) and manual calculation were not different statistically (Table 1)

Table 1 Correlation between manual constructed ring-width indices and ring-width index detrenched series constructed using ARSTAN program.

Tree-ring Index	Statistic	STD[1]	ARS[2]	RES[3]	INDEX[4]
STD	Pearson Correlation	1			
	P-value	-			
ARS	Pearson Correlation	0.808	1		
	P-value	0.000	-		
RES	Pearson Correlation	0.984	0.779	1	
	P-value	0.000	0.000	-	
INDEX	Pearson Correlation	0.950	0.746	0.946	1
	P-value	0.000	0.000	0.000	-

Notes: [1,2,3] Standard (STD), Arstan (ARS) and Residual (RES) chronologies were constructed using automatic curve fit detrending via ARSTAN program. [4] Tree ring chronology (Index) was constructed using manual curve fit detrending.

Based on the 15 year moving average of the mean, the standardized ring-width index (Figure 3b) from 1779 to 2008 was divided into three periods: the first period chronology (1779-1839) showed more rapid growth than average; the second period showed average growth (1840-1992); and the third period showed rapid growth (1993-2007). We quantitatively evaluated the chronology signal strength by using the expressed population signal or EPS (Wigley *et al*.,1984) which indicated how well the study site chronology estimate a theoretically infinite population. The part of the chronology, where replication (n) was adequate to accomplish an EPS ≥0.85, was regarded as dependable for climate reconstruction. The running RBar (Cook and Kairiukstis 1990), which measures correlation between ring-width series through time, was also calculated (Figure 4)

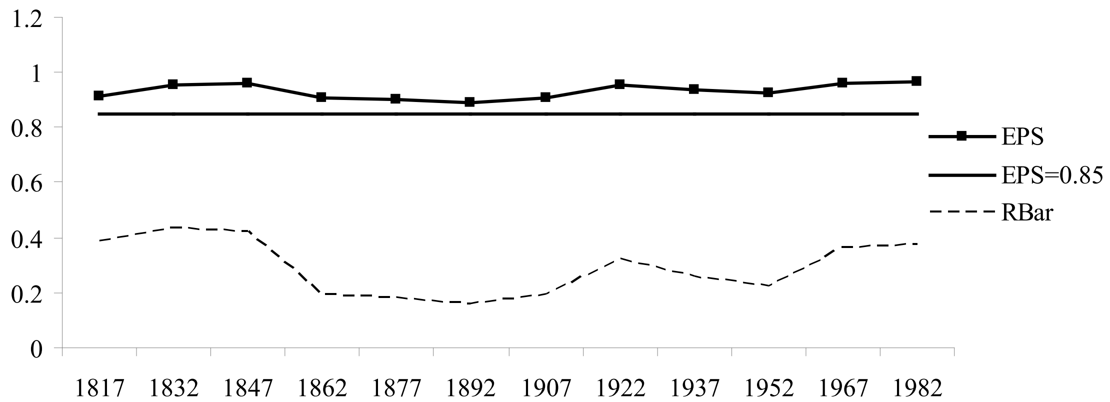

Figure 4 Running EPS statistic using a 15-year window, lagged 40 years, and Rbar.

Climate Response

To identify the climate-growth relationship of the pine trees, the nearest meteorological data (1953-2007) (Figure 2) were correlated with the standardized tree-ring chronology (Figure 3b). The chronology showed a strong significant positive correlation ($P<0.01$) with the current year temperature in October (Figure 5a) ($R^2 = 0.27$), and present year average temperature (Figure 5b) ($R^2 = 0.18$), and previous year average temperature (Figure 5c) ($R^2 = 0.22$). Other climatic factors showed negative relationships with the growth of the trees.

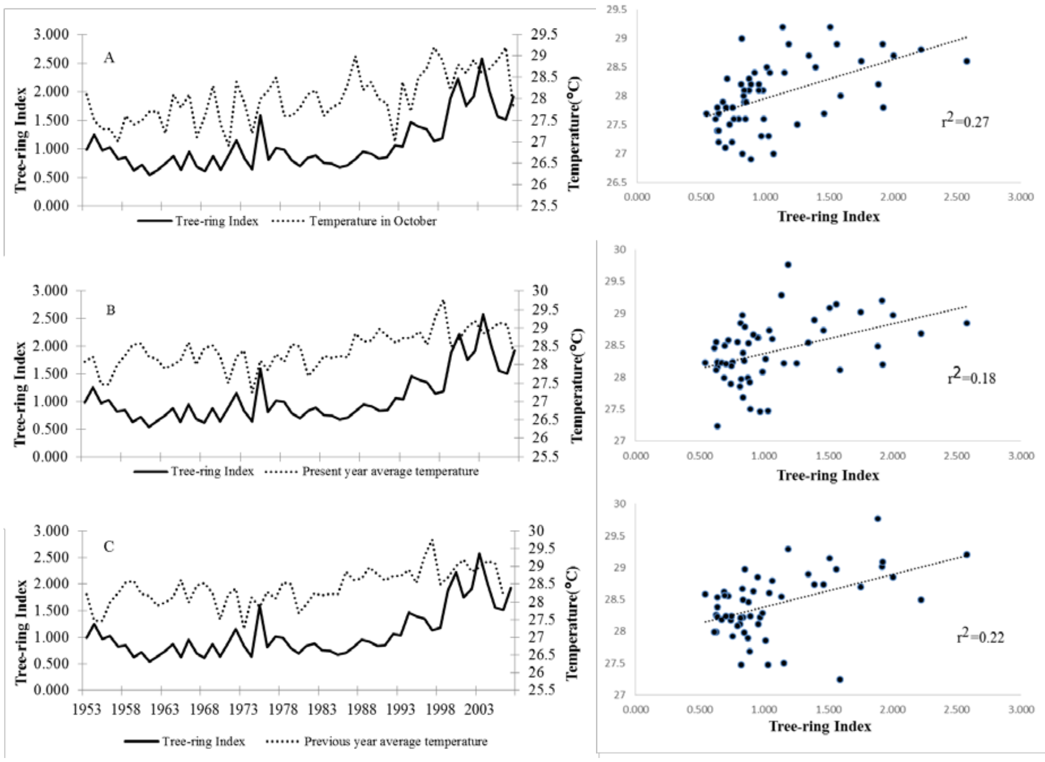

Figure 5 (A) Comparison of tree-ring index and current year temperature in October, (B) Comparison of tree-ring index and present year average temperature, (C) Comparison between previous year average temperature data and tree-ring index from 1953 to 2007 for *Pinusmerkusiiin* central Thailand.

The positive growth-temperature correlation suggested steady growth and an increase in temperature throughout the period 1840-1992, while in the prior (1779-1839) and the later periods (1993-2007), growth was above-average (Figure 3b) with values of 0.132 and 0.625, respectively.

Climate Reconstruction

The change in annual ring width of *Pinus merkusii* was related to temperature, rainfall, and relative humidity but exhibited the highest significant relationship with temperature. The results revealed that the current year temperature in October was the most important factor affecting tree-ring widths. Therefore, in this case, the October temperature was selected as the main variable for climate reconstruction. The data was split into an early period (1953-1978) for calibration and a late period (1979-2007) for verification (Figure 6). Linear regression was used to calculate the transfer function for October temperature reconstruction from the tree-ring chronology (1953-1978). The temperature reconstructed model is shown in Eq. (1):

$$\hat{Y}_t = 27.128 + 0.6295X_t \qquad \text{......(1)}$$

where: $\hat{Y}_t$ is the estimated October temperature value and X_t is the corresponding tree-ring index value (t in years in both cases).

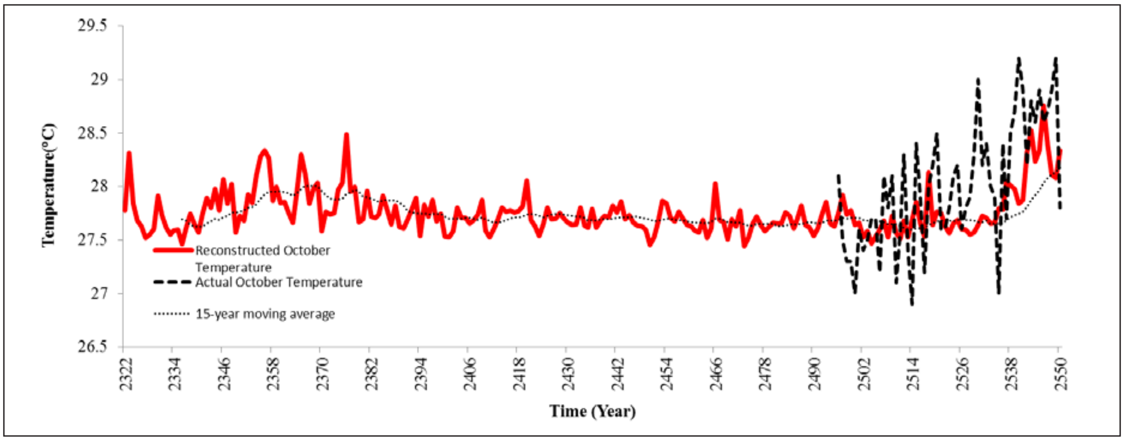

Figure 6 Actual October temperature (black) and October temperature reconstruction (red).

The actual and reconstructed data were compared and the calibration-verification statistics were calculated. The statistics of the calibration period had a significant correlation coefficient (r = 0.33, P<0.05), reduction of error statistic (RE = 0.11), and product means test (PM = 2.26) but, the value of sign test (s = 10) was not significant. The verification period statistical values had a significant correlation coefficient (r = 0.41, P<0.05), reduction of error statistic (RE = 0.42), product means test (PM = 4.19), and sign test (s = 9). Using the reconstructed model (Eq. 1) October temperature was reconstructed over central Thailand from 1779 to 2007. The October temperature reconstruction produced an average temperature of 27.75 °C and could explain the high fluctuation in temperature. The trend of reconstructed temperature in 1779-1839 increased to 27.84 °C and gradually decreased to a stable temperature of 27.68 °C in 1840-1992. In 1993-2007, the temperature rapidly increased to 28.17 °C (Figure 6).

Based on the October temperature reconstruction, derived from the spectral analysis, the tree-ring index revealed a temperature cycle every 2.1-5 years. There were also strong peaks around 57, 76 and 114 years (Figure 7).

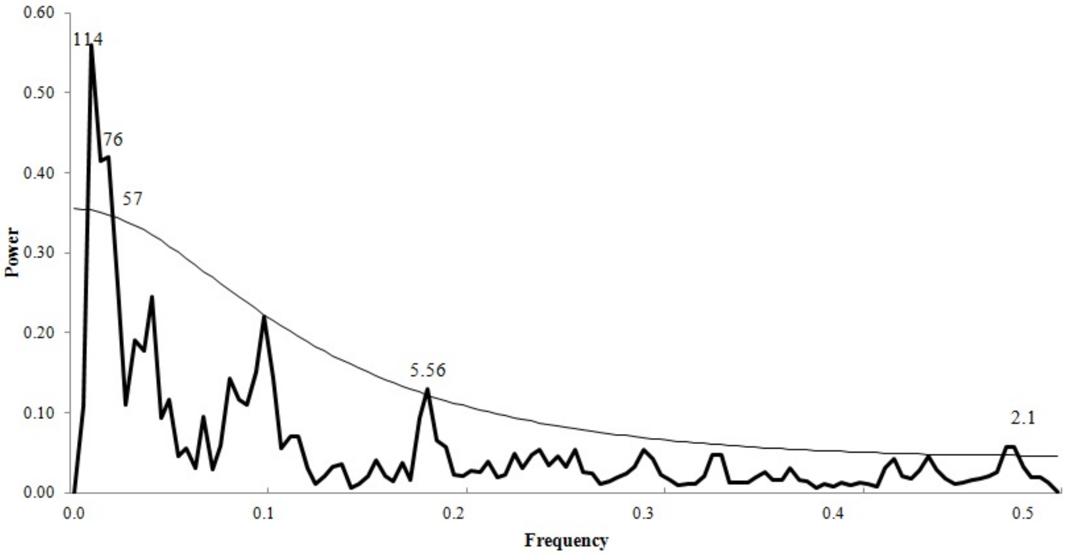

Figure 7 REDFIT procedure power spectra for October temperature reconstruction. Peaks above the solid line indicate significance at the 95% level of confidence ($P < 0.05$).

The climate-growth response of pine trees in Thailand has varying results. In the northern region, Duangsathaporn (2000) examined the effect of climate and the effect of thinning on the growth of *Pinus kesiya* and found that only rainfall in May affected tree growth. Hutameta and Pumijumnong (2003) found a positive correlation between rainfall in March and April and the growth of *P. merkusii.* Pumijumnong and Wanyaphet (2006) studied seasonal cambial activity and tree-ring formation of *P*. *merkusii* and of *P*. *kesiya* in northern Thailand and found that *P. merkusii* had a significantly positive relation with rainfall in the transition season and a significantly negative relation with temperature in the remaining months. They also found that *P. kesiya*, which has a shorter life span than *P. merkusii*, often showed a positive correlation with rainfall as well as with temperature in the remaining months. In the northeastern region, Buckey *et al*. (1995) and Boonchirdchoo (1996) found a positive relationship with temperature and a negative relationship with rainfall at the beginning of the rainy season; the pine ring widths showed a positive relationship to temperature and rainfall in the peak monsoon (September).

In the current study, the present and previous year average temperature, and the current year temperature in October, showed a strong positive correlation with ring-width index for *P*. *merkusii* in central Thailand. On the other hand, other climatic factors, for example, total monthly rainfall and average monthly relative humidity, showed a negative relationship with the growth of *P. merkusii*. Thus, it appears that the growth of *P. merkusii* in central Thailand can be explained by temperature changes. This result differs from previous studies in

Thailand because climatic data from this study site show a different pattern from other study sites (Figure 2). During dormancy (November to April) the rainfall at Phutoei National Park in 1953-2007 was near 50 mm, and then it increased in May, and dropped in June and during dormancy until August. The rainfall peaked from September to the end of October, as did humidity. Thus, under such conditions, rainfall and humidity and pine growth show negative relationships.

The reconstruction of October temperature showed a steady temperature in the period from 1779 to 1839. The temperature in this period was higher than the average temperature, similar to the SST records. The fluctuation in the reconstructed temperature was similar to coral records from Galapagos Island (Dunbar *et al*., 1994) which indicated very warm SST anomalies during the 1700s, and the periods from 1993 to present time, thus supporting the global warming phenomenon. Finally, based on the spectral analysis, the tree-ring index revealed a temperature cycle every 2.1-5 years which might be related to the influence of the ENSO.

CONCLUSION

A new *P. merkusii* tree-ring chronology from Phutoei National Park in central Thailand was extended back 230 years. The chronology was divided into three periods (1779-1839, 1840-1992, and 1993-2007); average growth rates in the first and third periods were higher than in the second period (0.132 and 0.625, respectively). The chronology also showed a high positive correlation ($P < 0.01$) with the current year temperature in October, the present year average temperature, and the previous year average temperature.

The reconstructed October temperature showed an average temperature of 27.75 °C. The warmer periods in 1779-1839 and 1993-2007 were higher than in the second period (1840-1992) by 0.16 °C and 0.49 °C, respectively. The tree-ring index revealed a temperature cycle every 2.1-5 years. There were also strong peaks around 57, 76 and 114 years. Conclusively, the growth of *P. merkusii* from Phutoei National Park could be applied to investigate climate change and global warming events.

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