Climate effects on the growth of *Pinus latteri* and *Pinus kesiya* at the Intakin Silvicultural Research Station, Chiang Mai Province, Thailand

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Abstract. *Naumthong M, Palakit K, Duangsathaporn K, Prasomsin P, Lumyai P. 2021. Climate effects on the growth of* Pinus latteri *and* Pinus kesiya *at the Intakin Silvicultural Research Station, Chiang Mai Province, Thailand. Biodiversitas 22: 2512-2519.* Relationship between the growth of two pine species, *Pinus latteri* and *Pinus kesiya*, and past climatic factors are studied. Standard dendrochronological techniques were used on 40 core samples obtained from 20 trees from each species to cross-date tree-ring width and determine the growth patterns of each species. Over a period spanning from 1980-2019 *(P. latteri)* and 1984-2019 *(P. kesiya)*, the calculated mean ring-width values were 0.596 and 0.430 cm per year, respectively. An analysis of the relationship between tree-ring width of *P. latteri* and climatic data indicated a positive correlation with the relative humidity in April. However, a negative correlation was observed with the temperature in April and August. The factors limiting the growth of *P. latteri* the most were the temperature in August (r^2=0.228; P<0.01). The index constructed for *P. kesiya* indicated a positive correlation with extreme minimum relative humidity in December and extreme maximum temperature in March. The factors limiting the growth of *P. kesiya* with a significant correlation, were the relative humidity in April (r^2=0.173) and temperature in May (r^2=0.184). These results can be used to plan the management of forest plantations and to select suitable areas for the cultivation of pine trees in Thailand.

Keywords: Climate growth response, limiting factor, Pearson correlation coefficient, tree-ring width index, tree ring chronology

INTRODUCTION

Climate change is a very important environmental issue around the world, with an even more relevance on regional scales in specific zones, mainly resulting from various anthropogenic activities. According to the World Metrological Organization report filed in the United Kingdom, it was found that the average global temperatures during 2018 increased by 1.42 °F around the world relative to the 20th-century (NOAA 2019). These effects of climate change can have several impacts on both human and natural resources, especially forest resources, which is an important resource that benefits human beings both directly and indirectly. Studying the past climate could provide some evidence as to the conditions during those times, for which scientists use proxy data to reconstruct and study the climate in the past. Through the techniques of dendrochronology, tree rings can be used to determine the relationship with climate data such as rainfall and temperature. The effects of climate can yield different results depending on the study site and species from which the tree-rings have been derived (Palakit et al. 2015a, 2015b, 2018, 2019; Susatya and Yansen 2016).

Extensive dendrochronological studies have been conducted in Thailand and include species like *Pinus latteri* Mason. The species has been used to determine the response to rainfall throughout the year at Thung Salaeng Luang, Phitsanulok province and *P. kesiya* Royle ex Gordon presented positive response with rainfall and

negative with November temperature at the Nam Nao site, Phechabun Province (Buckley et al. 1995), as these species respond readily to the changes in climatic factors in Thailand. *P. latteri* and *P. kesiya* are found extensively in the northern and northwestern regions of Thailand. It has been reported that pine trees, found in various parts of Thailand, respond to climate variability in terms of rainfall in May during the beginning of the rainy season and to variations in temperature during the transition from dry to wet season in April to May (Pumijumnong and Wanyaphet 2006; Pumijumnong and Eckstein 2011). Other previous studies have reported on the effect of climate changes on the growth ring width in teak and pine (Buckley et al. 2007; Pumijumnong 2012; Duangsathaporn and Palakit 2013; Palakit et al 2015b, 2019; Buajan et al. 2016; Muangsong et al. 2016, 2018; Sangram et al. 2016; Auykim et al. 2017; Lumyai and Duangsathaporn 2017a, 2017b; Preechamart et al. 2018; Khantawan et al. 2019; Buareal et al. 2020; Lumyai et al. 2020; Pumijumnong and Palakit 2020; Rakthai et al 2020).

The two native pine species in Thailand, *P. latteri* and *P. kesiya*, have been used to study the changes in growth as a result of climate variability using dendrochronology. These studies compared the species sampled from various natural forests, and have reported the differences in growth based on landscape)Buckley et al 1995; Pumijumnong and Wanyaphet 2006; Pumijumnong and Eckstein 2011(. At present, the natural forests are unable to fulfill the demand and quality of the timber supplied to the timber industry

because the natural forests are difficult to manage, has a long interval between tree felling cycle and is economically not feasible. Forestry statistics calculated for the 5 year period of 2009-2014, however, indicate that Thailand imported pine timber and lumber worth 1523 million Baht/year. Even though there is a great potential for pine plantations in Thailand, with additional economic and environmental benefits, the area under pine plantations is very limited. Forest plantations can help to meet such demands, resulting in economic benefits to the plantation owners.

The objective of this study was to determine the relationship between climatic factors which can affect the development of tree-ring width in forest plantations of *P. latteri* and *P. kesiya* growing at the Intakin Silvicultural Research Station located in Chiang Mai Province, Thailand.

MATERIALS AND METHODS

Study site

The study site at the Intakin Silvicultural Research Station, Chiang Mai Province, is located on a 45-kilometer stretch next to the Chiang Mai-Fang road, Highway 107, Inthakin Subdistrict, Mae Taeng District, Chiang Mai Province. The station is located at a latitude of 19°09'

02''N and longitude of 98°56' 5''E, at an altitude of 400 meters above sea level. The climate data were obtained from the Thai Meteorological Department, located in the Chiang Mai Province (18°46'17''N and longitude of 98°58'21''E), which is at a distance of around 47 kilometers from the study area. The average temperature around the site is 26 °C with the maximum temperature reaching around 32 °C, while the average minimum temperature fluctuates around 20.9 °C. The area receives an average annual rainfall of 1,136 mm, with an average relative humidity of around 70 %. The forest is broadly classified as a deciduous forest. The study site covers an area of approximately 1,392 rai (222.72 ha), which is an area of *P. latteri* 12 rai (1.92 ha), planted in 1978 and an area of *P. kesiya* 125 rai (20 ha), planted in 1981. (Figure 1). The local climate data for the period of 1980 to 2019 included the total monthly rainfall, mean monthly relative humidity (RHmean), mean maximum monthly relative humidity (RHMmax), mean minimum monthly relative humidity (RHMmin), extreme minimum monthly relative humidity (RHEmin), mean monthly temperature (Tmean), mean maximum monthly temperature (TMmax), mean minimum monthly temperature (TMmin), extreme maximum monthly temperature (TEmax), and extreme minimum monthly temperature (Temin) (Figure 2).
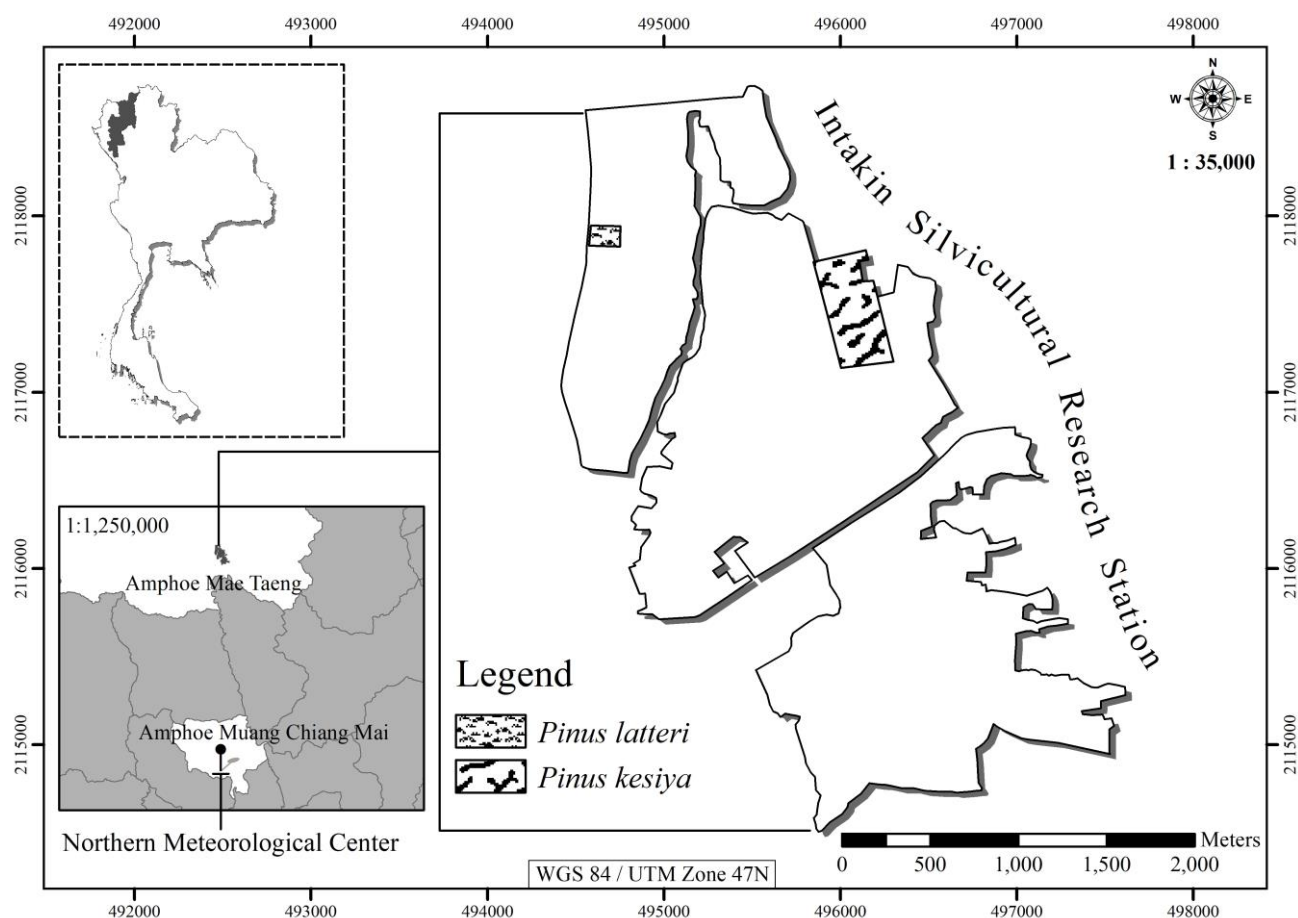
Figure 1. Map showing the study site of *Pinus latteri* and *P. kesiya* plantation at the Intakin Silvicultural Research Station in Chiang Mai Province, Thailand
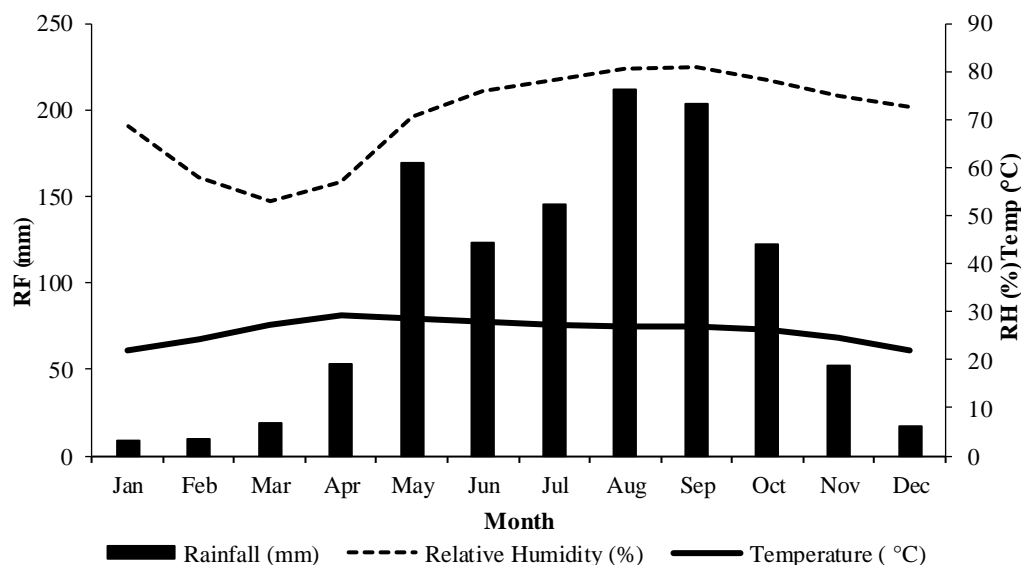
Figure 2. The local climate data, including total monthly rainfall, mean monthly relative humidity, mean monthly temperature, as published by the Thai Meteorological Department

Fieldwork sample collection

The cores samples of *P. latteri* and *P. kesiya*, growing in the plantation, were taken during June 2020, with a total of 40 cores sampled from 20 living trees of each species. Two core samples from each tree were taken using an increment borer at a breast height of 1.30 meter in the opposite directions of the stem. The core samples were selected based on the criteria of dominance, crown symmetry, and location in a well-drained area. Additionally, it was ensured that the selected tree did not have any obvious bruises, scars, unusual characteristics, and other issues, for instance, disease, insect disturbance, and fire damage. At the Laboratory of Tropical Dendrochronology, Faculty of Forestry, Kasetsart University, Bangkok, Thailand, the sample cores were prepared according to standard dendrochronological techniques (Stokes and Smiley 1968). All the samples were dried at room temperature, glued and mounted onto wooden supports with the cross-sectional position pointing upward. The samples were scrubbed with sandpapers number 120, 220, 300, and 400 until the tree-ring surface was visible enough under a microscope.

Ring width measurement and construction of tree-ring index

The tree-ring widths were compared for their growth patterns within a tree and between trees to classify the annual rings, false rings, or missing rings, using cross-matching techniques. Subsequently, the tree-ring widths were used to construct a time series for each year with cross-dating techniques (Ferguson 1970; Fritts 1976). The samples made using cross-matching and cross-dating were observed using a 4×-40× stereo microscope. The Velmex measuring system was used to measure the tree-ring width at a resolution of 0.01 mm and the results were displayed

on a computer through the J2X program (Voor Tech Consulting 2008). The accuracy of tree-ring growth and a given calendar year was verified using the COFECHA program (Holmes 1983). The sample cores passed the significance test at a 99% confidence level and a Pearson correlation coefficient of 0.5155. The tree-ring width was analyzed using appropriate statistics indicating the relevant properties, such as correlation with master, standard deviation, autocorrelation, and mean sensitivity (Fritts 1976). Later, the tree-ring width index was standardized to remove any growth or age trends using the ARSRTAN program and autoregressive modeling (Cook and Kairiukstis 1990). The detrending of analyzed tree-ring width index was done using a negative exponential curve or a straight line with a negative slope by dividing the actual value from the predicted value and dividing the new value by the average and was labeled as the master chronology or tree ring index. The reliability of acceptable cores samples using the expressed population signal (EPS) was $\geqq 0.85$ (Wigley et al. 1984). Finally, a running RBar, which measures the correlation between ring-width series through time, was also calculated (Cook and Kairiukstis 1990).

Climate-growth response analysis and limiting factors

The correlation of ring widths of *P. latteri* and *P. kesiya* with the climate data was determined, the ring-width data being the dependent variable and the climatic data as the independent variables. Statistical measures were determined which included simple correlation, multiple regression, stepwise regression as indicated by the Pearson's correlation coefficient (r), and the coefficient of determination (r^2).

RESULTS AND DISCUSSION

Tree-ring chronology statistics

A total of 40 samples from 20 *P. latteri* trees passed the cross-matching, were cross-dated, and the accuracy of time series values was determined with the COFECHA Program (Holmes 1983). The crossed ring width data could be extended back by up to 40 years, covering a period from 1980 to 2019. These sample cores passed the significance test at a 99% confidence level and had a Pearson correlation coefficient of 0.5155. The mean series inter-correlation was 0.586, the standard deviation was 0.416, the average mean sensitivity was 0.306, and the mean length of the series was 35 years. The mean ring-width value was 0.596 cm per year (Figure 3A). The tree-ring width index covered a period from years 1982 to 2019 (Figure 3C).

A total of 40 samples from 20 *P. kesiya* trees were successfully cross-dated. The tree-ring widths passed the significance test at a 99% confidence level with a Pearson correlation coefficient of 0.5155. The crossed ring width data could be extended back by up to 36 years, covering a period from 1984 to 2019. The mean series inter-correlation was 0.698, the standard deviation was 0.449, the average mean sensitivity was 0.364, and the mean length of series was 34.8 years (Figure 3A). The mean ring-width value was 0.430 cm per year. The tree-ring index of *P. kesiya* covered a period from years 1984 to 2019 (Figure 3D).

We quantitatively evaluated the chronology signal strength by using the expressed population signal or EPS (Wigley et al. 1984). The EPS for the constructed index of *P. latteri* (Figure 3D) during the period from 2000 to 2019 and *P. kesiya* during 1989 to 2019 was 0.85 greater than the standard value, and was accepted as being reliable. The running Rbar (Cook and Kairiukstis 1990), or the autocorrelation of the tree-ring index with time, was determined for many samples during 2005 – 2009 for *P. latteri* and similarly for several *P. kesiya* samples during 1989 – 1999 (Figure 3E). Overall, indices of both types of pine in the study area indicated sufficient replication.

P. latteri grew rapidly between 1990 – 2002 and after that, the growth declined until the year 2019. *P. kesiya* experienced faster growth during 1984 – 1991 relative to that of *P. latteri* and after that, the growth was noticeably lower. When *P. latteri* and *P. kesiya* of the same age were compared at during the years between 1984 – 1990, *P. kesiya* had better growth than *P. latteri*, but during 1991 – 2004 it was observed that *P. latteri* grew at a faster rate than *P. kesiya* until the period from 2005 – 2019, when the growth of *P. latteri* and *P. kesiya* declined at a similar rate.

The mean ring-width values of *P. latteri* were higher than *P. kesiya*. It can be concluded that at first, the growth of *P. latteri* was high and then gradually decreased, while the growth of *P. kesiya* was comparatively slower. The growth rates of the two pine species in this plantation can be considered as being relatively high compared to that reported by Chaudhary and Bhattacharyya (2002). *P. kesiya* growing on the Shillong plateau in northeast India had an average growth of ring-widths between 0.16 - 0.24 cm per year. Missanjo E. (2016) indicated that the average growth of *P. kesiya* ring in Malawi was around 0.42 cm per year. Pumijumnong and Eskstein (2011) studied *P. latteri* and *P. kesiya* growing in a natural forest in northwestern Thailand and found that these pines have a mean growth of ring-widths approximately between 0.2 - 0.4 cm per year. Lumyai and Duangsathaporn (2017) reported that the *P. latteri*, growing in the Phutoei National Park in Suphan Buri province, central Thailand, had a mean ring-width growth of 0.86-1.63 cm per year. Yordtong et al. (2019) studied the *P. latteri* at the Phu Kradueng National Park, Loei Province, Thailand and estimated a mean ring-width growth of 0.358 cm per year. Lumyai et al. (2020) studied *P. latteri* and reported a mean ring-width of .113 cm per year at a study site in Chiang Mai province, Thailand. The study found that *P. latteri* and *P. kesiya* in the plantation had a higher growth compared to pine growing in natural forests and also reported a higher growth rate for *P. latteri* relative to *P. kesiya*. Therefore, it can be concluded that *P. latteri* should be promoted in forest plantations around Thailand.

### Climate-growth response and limiting factors

The relationship between growth of *P. latteri* as estimated by its tree-ring index with the climate data was analyzed. We found a significant positive correlation (P<0.05) with the relative humidity in April (r = 0.357) and a significant negative correlation (P<0.05) with Tmean in April and August (r = -0.345 and -0.365, respectively). Rainfall, RHMmax, RHMmin, RHEmin, TMmax, TMmin, TEmax, and Temin did not have a significant correlation with the tree-ring index. The relationship with TMmax during the October of previous year was found to have a significant negative correlation (r = -0.418; P<0.05) and a significant positive correlation (P<0.05) was observed with TMmin in April (r = 0.369) of the previous year (Figure 4A, 4B). Factors limiting the growth of tree-ring index of *P. latteri* were analyzed with multiple regression. It was found that the temperature in August influenced the growth with a significant correlation (r^2 = 0.228; P<0.01) and can be written mathematically as in Eq.1:

$$\text{Index}_{PL} = 4.713 - 0.138 \, (\text{Tmean}); \, r^2 = 0.228, \,\ldots\ldots\ldots \text{(eq.1)}$$

Where; Index_{PL} is the tree-ring index of *P. latteri* estimated by using the temperature in August and Tmean is the mean temperature for each year corresponding to the tree-ring index.
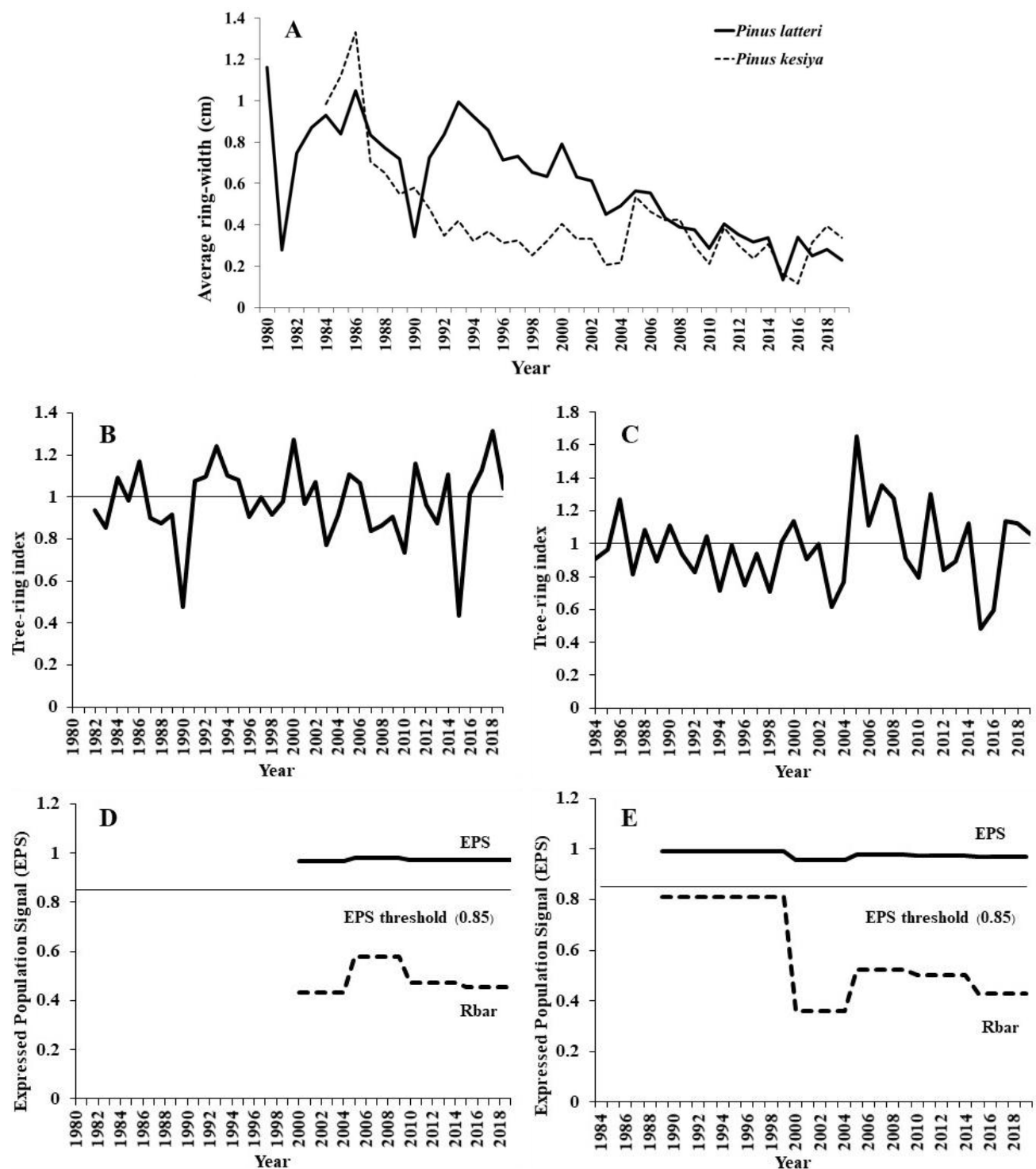
Figure 3. A. Mean ring-widths of *Pinus latteri* (solid line) and *P. kesiya* (dashed line). B. Standardized chronological index of *P. latteri* and C. *P. kesiya*, respectively. Running EPS (solid line) and Rbar (dashed line) values for the reconstructed ring indices of: D. *P. latteri* and E. *P. kesiya*.
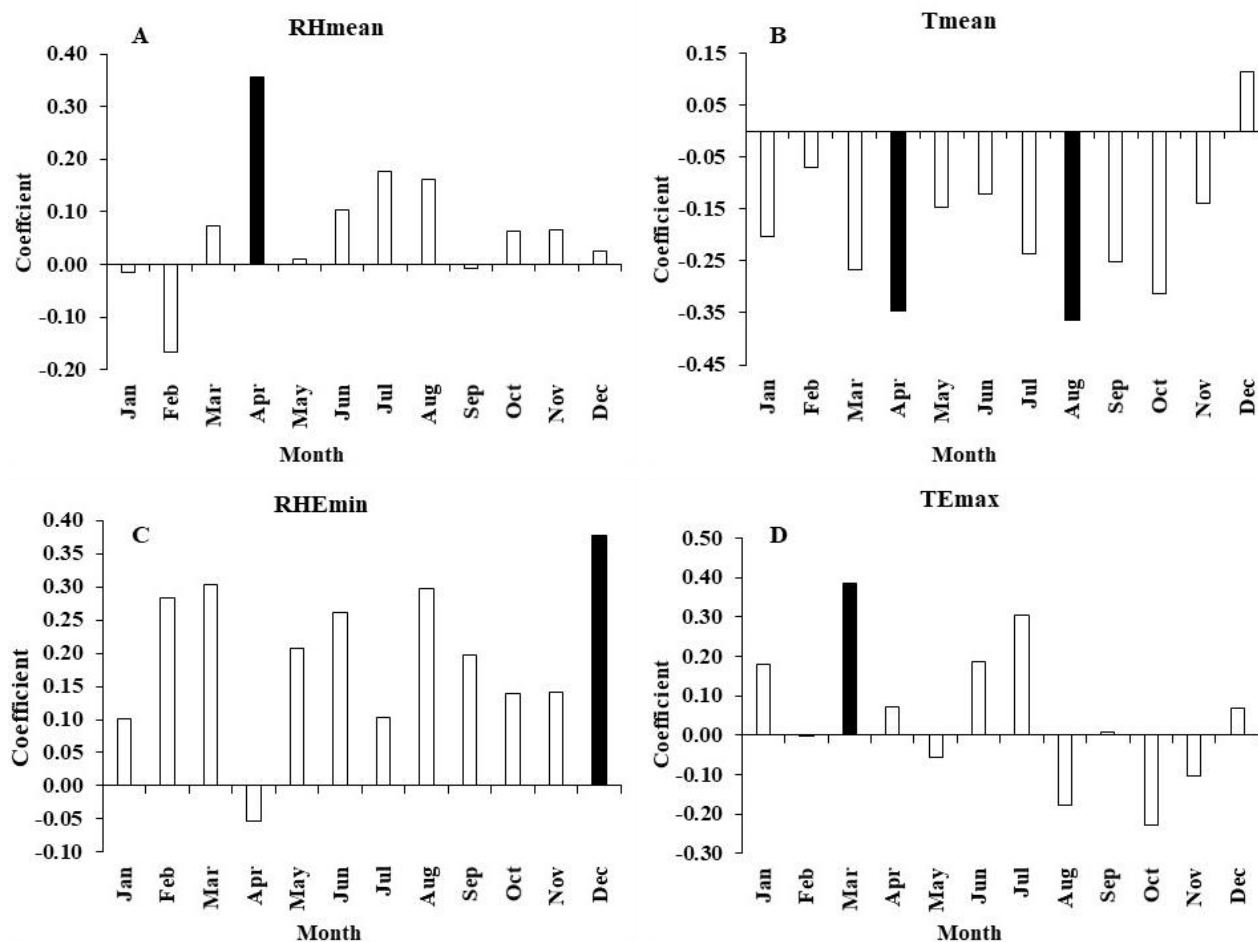
Figure 4. A. and B. correlation coefficient between the climatic data (RHmean and Tmean) and the growth of *P. latteri* tree-ring width. C. and D. correlation coefficient between the climatic data (RHEmin and TEmax) and growth of *P. kesiya* tree-ring width. The black bars indicate a significant correlation.

We found a significant positive correlation (P<0.05) with RHEmin in December (r = 0.377), and a significant positive correlation (P<0.05) with TEmax in March (r = 0.385) with the growth of tree-ring index of *P. kesiya*. The other climate variables, including rainfall, RHmean, RHMmax, RHMmin, Tmean, TMmax, TMmin, and TEmin did not have a significant correlation with the tree-ring growth, while a significant positive correlation (P<0.05) was found with Tmean in March and April (r = 0.357 and 0.368, respectively) of the previous year. TMmax in January (r = 0.383) and TEmax in March of the previous year (r = 0.427) had a significant positive correlation (P<0.05), while a significant negative correlation (P<0.05) was observed with TEmax in June (r = -0.367) of the previous year (Figure 4C, 4D). The relative humidity in April (r^2 = 0.173) and Tmean in May (r^2 = 0.184) influenced the growth of *P. kesiya*, with a significant correlation (P<0.05), as indicated by Eq.2.

$$Index_{PK} = 3.466 - 0.088 \ (Tmean); \ r^2 = 0.184, \ \ldots\ldots\ldots (eq.2)$$

Where; $Index_{PK}$ is the tree-ring index of *P. kesiya* estimated using the temperature in May and Tmean is the mean temperature for each year corresponding to the tree-ring index.

A growth comparison was made between *P. latteri* and *P. kesiya* in the Intakin Silvicultural Research Station, which is a forest plantation managed according to silvicultural practices. We found that *P. latteri* had a better growth compared to *P. kesiya*, as indicated by a mean ring-width of 0.166 cm per year. Due to the appropriate elevation for growing. Usually, *P. latteri* grow well at an altitude of 300-700 meters above sea level)Northern Silvicultural Research Center 2019). The results of the present study found that Tmean in August of each year (middle of the rainy season) had a significant correlation (P<0.01) with the tree-ring index of *P. latteri*. This was found to be the month receiving the highest rainfall with a high relative humidity. As a result, the temperature in August dropped and affected the growth of *P. latteri*. Therefore, the factor limiting the growth of *P. latteri* was Tmean. Tmean in May of each year (period spanning the dry season and the beginning of the rainy season) was significantly correlated (P<0.05) with the ring growth and was the limiting factor for *P. kesiya*, resulting in increased rainfall and higher relative humidity, lowering the temperature as well as growth response of *P. kesiya*. We conclude that the *P. kesiya* growth was lower than *P. latteri*. Therefore, *P. kesiya* should be planted in open

forest areas, in order to vegetate the area and after becoming a pioneer species that can rapidly grow and be used to reclaim the area. *P. latteri* should be promoted in a forest plantation to increase the economic value of the forest for trade and export to various countries.

Climate variability affected the growth of *P. latteri* and *P. kesiya* in Thailand differently. The results of the present study are consistent with the results from several previous studies reporting that *P. latteri* can grow well in the post-monsoon (November to February) period, and is its optimal growing season. We found that the Tmean in August is an important factor in the growth of *P. latteri*. The highest rainfall in August and the mean relative humidity in September induce *P. latteri* growth similar to a previous study conducted in Thailand by Yordtong et al. (2019), who found a significant positive correlation (P<0.05) between the growth response of *P. latteri* with the TMmin in October and RHmean in March, October, and November were the main limiting factors for *P. latteri*. An increase in the TMmin at the end of the year, in addition to an increase in the RHmean at the end of the year to the beginning of the next year, would increase the growth rate of *P. latteri*. In contrast, the temperatures tend to drop from May to January.

The temperatures declined in the rainy season induce *P. latteri* growth as similar as the study of Lumyai et al. (2020) who studied the influence of climate on the growth of *P. latteri* in the northern region of Chiang Mai, Thailand. The result found a significant negative correlation (P<0.01) with the mean temperature in August was reported and the temperature in September was the limiting factor affecting the growth of *P. latteri*. Lumyai and Duangsathaporn (2017a) studied the relationships between tree growth and climatic data in *Pinus merkusii* in Central Thailand and found that the chronology had a high positive correlation (P<0.01) with the temperature of current year in October Which was found to have a temperature of 27.75 °C. This was the period when the temperature dropped until the growth of *P. latteri* increased again. This showed that an optimum temperature drop can result in a better growth of *P. latteri*. This is also consistent with the research of Rakthai et al. (2020), who studied the growth of *P. latteri* at three sites in Northeastern Thailand and found that the growth of *P. latteri* had a significant negative correlation (P<0.05) with the temperature (mean, maximum and minimum) from April to August. Buckley et al. (2007) analyzed the growth of rings in *P. latteri* growing in Lao P.D.R. and found a significant positive correlation (P<0.05) with the maximum temperature in August to September, which was the main limiting factor controlling the growth of *P. latteri*.

On the other hand, the growth in *P. kesiya* was found to be most affected by the relative humidity in April and the temperature in May, which is a period spanning the dry and rainy season It was found that the increase in relative humidity and lowering of temperature during the early rainy season resulted in an increase in growth rate of *P. kesiya*. This was found to be consistent with the research of

Pumijumnong and Eckstein (2011), who studied the tree-ring widths of *P. latteri* and *P. kesiya* and found that their growth was negatively correlated (P<0.05) with the mean temperature during the pre-monsoon period from March to May. As such, the change from the dry season to the rainy season was the period that affects the growth of *P. latteri* and *P. kesiya*. Pumijumnong and Wanyaphet (2006) studied the seasonal cambial activity and tree-ring formation in *P. latteri* and *P. kesiya* and found that the growth in both the species had a positive correlation with the mean temperature during November to July and a negative correlation with mean temperature during March to October. Chaudhary and Bhattacharyya (2002) studied the tree rings of *P. kesiya* in Shillong, India and found a positive and significant correlation with the temperature and rainfall in during March. From the present study, our findings are consistent with the previous studies which conclude that *P. kesiya* can grow well during the pre-monsoon period (May to October). Pumijumnong et al (2021) studied climate control of cambial dynamics and tree-ring in *P. latteri* and *P. kesiya* and found that the growth in both the species had a positive correlation with the relative humidity in April and May. This study found temperature is the important factor in tree-ring width of native pines in Thailand as similar as the study of Wang et al. (2017) who studied Korean pines growing and reported that temperature is the key limiting factor in controlling the growth of Korean pine

In summary, mean ring-width values of *P. latteri* and *P. kesiya* were 0.596 and 0.430 cm per year, respectively. A total of 40 samples from 20 *Pinus latteri* Mason trees passed cross-dated. The crossed ring width data could be extended back by up to 40 years, covering a period from 1980 to 2019. The mean series inter-correlation was 0.586, the standard deviation was 0.416, the average mean sensitivity was 0.306, and the mean length of the series was 35 years. A total of 40 samples from 20 *Pinus kesiya* trees were successfully cross-dated. The crossed ring width data could be extended back by up to 36 years, covering a period from 1984 to 2019. The mean series inter-correlation was 0.698, the standard deviation was 0.449, the average mean sensitivity was 0.364, and the mean length of series was 34.8 years. The factors limiting the growth of *P. latteri* the most were the temperature in August. The factors limiting the growth of *P. kesiya* were the relative humidity in April and temperature in May, that temperature is the key limiting factor in controlling the growth of pine in Thailand, this information can be used to select planting area for pine trees that is suitable for each climate.

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