Effects of Climate Variability on Monthly Growth of *Aglaia odoratissima* and *Hydnocarpus ilicifolia* at the Sakaerat Environmental Research Station (SERS), Northeastern Thailand

Kritsadapan Palakit [1*]***, Khwanchai Duangsathaporn*** [2]***, Somkid Siripatanadilok*** [3]***, Pichit Lumyai*** [2]

[1] *Faculty of Environment and Natural Resource Studies, Mahidol University, Nakhon Pathom, Thailand.*
[2] *Laboratory of Tropical Dendrochronology, Department of Forest Management, Faculty of Forestry, Kasetsart University, Thailand*
[3] *Department of Forest Management, Faculty of Forestry, Kasetsart University, Thailand*

Abstract

The research objective was to investigate effects of climate variability on monthly growth of *Aglaia odoratissima* and *Hydnocarpus ilicifolia* which are the dominant tree species in lower canopies of dry evergreen forest and generally found at the Sakaerat Environmental Research Station (SERS), northeastern Thailand. For one year of the investigation, monthly data of tree leaf phenology, inside bark diameter (IBD) and outside bark diameter (OBD) increments were examined. These data were related to soil moisture content and climatic data of monthly rainfall, temperature and relative humidity. The results showed that leaf phenology of *A. odoratissima* and *H. ilicifolia* illustrated leaf maturation throughout the year, while young leaves were abundant in the rainy season and leaf abscission was rarely found throughout the year. The IBD increments of these species on transverse surfaces could be detected throughout the year and the most rapid increments were detected in the rainy season, while OBD increments of both species shrank in the dry season and swelled in the rainy season. Using path analysis (PA), climate variability was found to be significantly related to leaf phenology of *A. odoratissima* and IBD increments of *H. ilicifolia*; and it was also significantly related to OBD increments of both species.

Keywords: Leaf phenology / Outside bark diameter/ Path analysis / Inside bark diameter

1. Introduction

Forests are extremely responsive to climate change and variability; it has been shown by observations from past research, experimental studies, and simulation models (Andreu et al., 2007; Nitschke and Innes, 2008; Polgar and Primack, 2011). Tree-ring analysis (called dendrochronology) is widely and successfully used to explain long-term climatic effects of tree growth especially in the temperate and boreal regions (Garcia-Suarez et al., 2009; Trouet et al., 2013). The dendrochronologists attempted to extend their research to the tropical and subtropical regions due to increasing demand for a better understanding of global climate dynamics associated with the gap of the paleoclimatic information in the tropics (Buckley et al., 1995; Pumijumnong et al., 1995; D'Arrigo et al., 1997; Pumijumnong and Wanyaphet, 2006; Pumijumnong and Eckstein, 2011). However, the study of climate-growth response using the technique of tree-ring analysis is still limited and the question of which tree species form annual rings and respond to climate are not yet solved. Additionally, the one criterion of tree selection for climate-growth studies is focused on dominant trees with non-suppression by the nearest trees (Fritts, 1976). This traditional procedure in tree-ring analysis is suitable for distinct annual ring species with the upper canopy but is not appropriate for indistinct and non-distinct annual ring species with the lower canopy. Therefore, in this paper, we investigated monthly growth of two evergreen species within distinct annual ring formation, namely *Aglaia odoratissima* and *Hydnocarpus ilicifolia*, in order to understand the effects of climate variability on their growth in the lower canopy. The study can be applied to confirm the principle of dendrochronology in tree selection for climate-growth relationship and climatic reconstruction analysis. Additionally, in forest management, the study illustrates the benefit of the emergent and upper forest canopy in local climatic stabilization which is suitable for tree species in the lower canopy growing throughout the year.

2. Methodology

2.1 The Study Site

The study site was located at the dry evergreen forest of the Sakaerat Environmental Research Station (SERS) in Udomsap Sub-district, Wang Nam Khiao District, Nakhon Ratchasima Province, northeastern Thailand (Figure 1). The SERS occupies an area of 80 km² on the edge of the Khorat Plateau, at longitude 101° 51 E and latitude 14° 30 N. It rises from 250 m above mean sea level to 762 m at the top of its highest mountain. The dry evergreen forest has a dense and three-storey canopy which is dominated by the upper canopy species ranging from 23-38 m high such as *Hopea ferrea*, *Lagerstroemia duppereana*, *Irvingia oliveri and Shorea*

*Corresponding author:
E-mail: kritsadapan.pal@mahidol.ac.th

henryana. The majority of the lower canopy species ranging from 16-22 m high include *Walsura trichostenon, Memecylon caeruleum, Hydnocarpus ilicifolia, and Aglaia* spp. The lowest layer is 4-14 m high tree species such as *Memecylon ovatum, Ixora ebarbata,* and *Randia wittii* (Thompson and Landsberg, 1975; Lamotte et al., 1998).

The climatic condition at SERS is tropical with no occurrence of frost. The winter is cool and dry, while the summer is hot and humid.

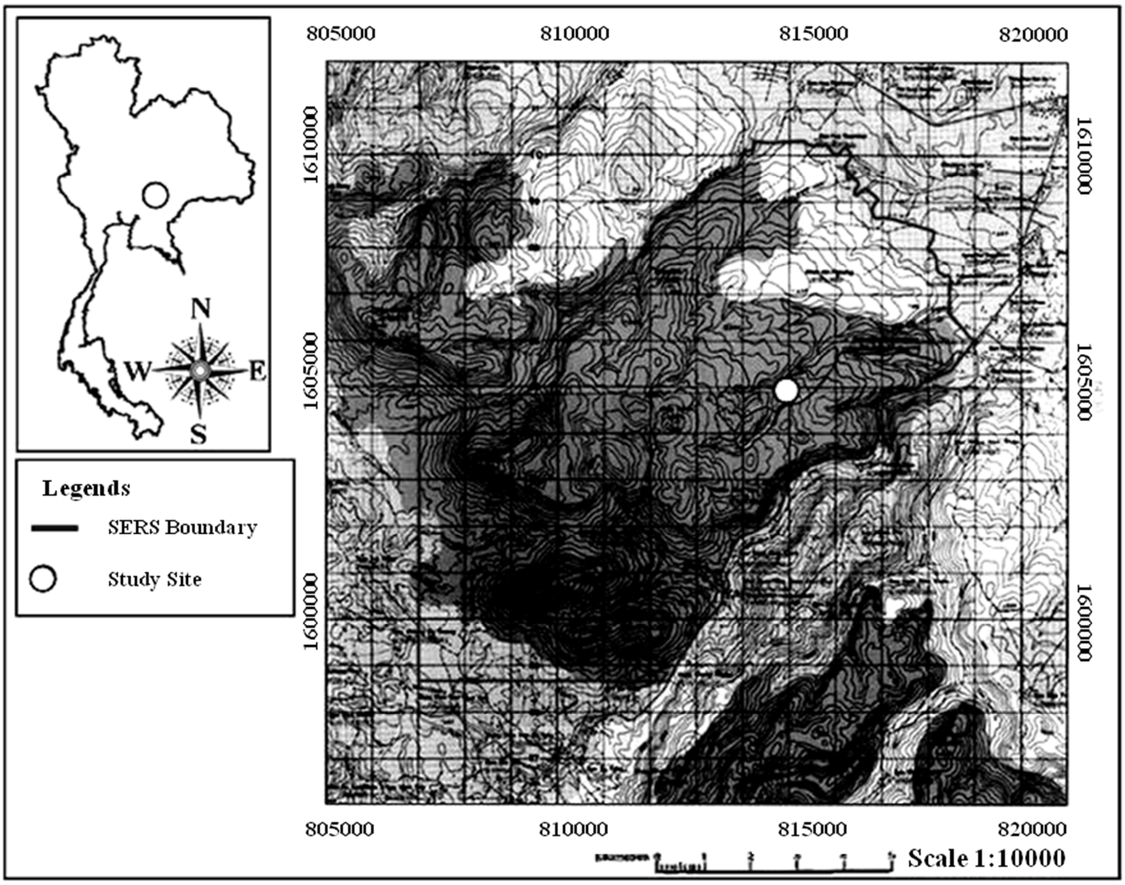

Figure 1: The study site at Sakaerat Environmental Research Station (SERS)

Mean maximum temperature is 35 °C, and mean minimum temperature is 16 °C. The wet season generally occurs from May to mid-October, with rainfall peaks in May and September. The average annual precipitation is 1,200 mm. Climatic data during the investigated periods derived from SERS are shown in Figure 2. Gray band in Figure 2a indicated dry period in November 2009-February 2010.

2.2 Methods

Two dominant species of the lower canopy, namely *A. odoratissima* (code AO01-AO06) and *H. ilicifolia* (code HI01-HI06) were selected. Six trees of each species which were; healthy, located on good drained area, and had symmetrical crowns and straight trunks were studied. Each tree location was marked using Global Positioning System (GPS). Leaf phenology including leaf flushing (LF), mature light green leaves (MLL), mature dark green leaves (MDL) and leaf abscission (LA),was routinely investigated once a month for a year in September 2009 till September 2010 using visual estimates with binoculars (O'Brien et al., 2008; Vitasse et al., 2009). The observer scored 0 for a bare crown, 1 for > 0–20 percent, 2 for > 20–40 percent, 3 for > 40-60 percent, 4 for > 60-80 percent and 5 for > 80 percent of the crown cover occupied by each class.

Outside and inside bark diameter increments were other periodic growth investigations. Outside bark diameter increment (OBD) at breast height (130 cm) was recorded using a modified manual band dendrometer with a 0.1 mm accurate vernier scale (Figure 3a). The measurements of OBD were taken for a year; coincided with the studies of leaf phenology. Inside bark diameter increments (IBD) were studied using the techniques of cambial wounded marking (Figure 3b). Once a month, cambial zones of the selected trees were injured in order to mark and investigate the boundaries of monthly growth zone and cell differentiation. A Year Later when the markings were completed,

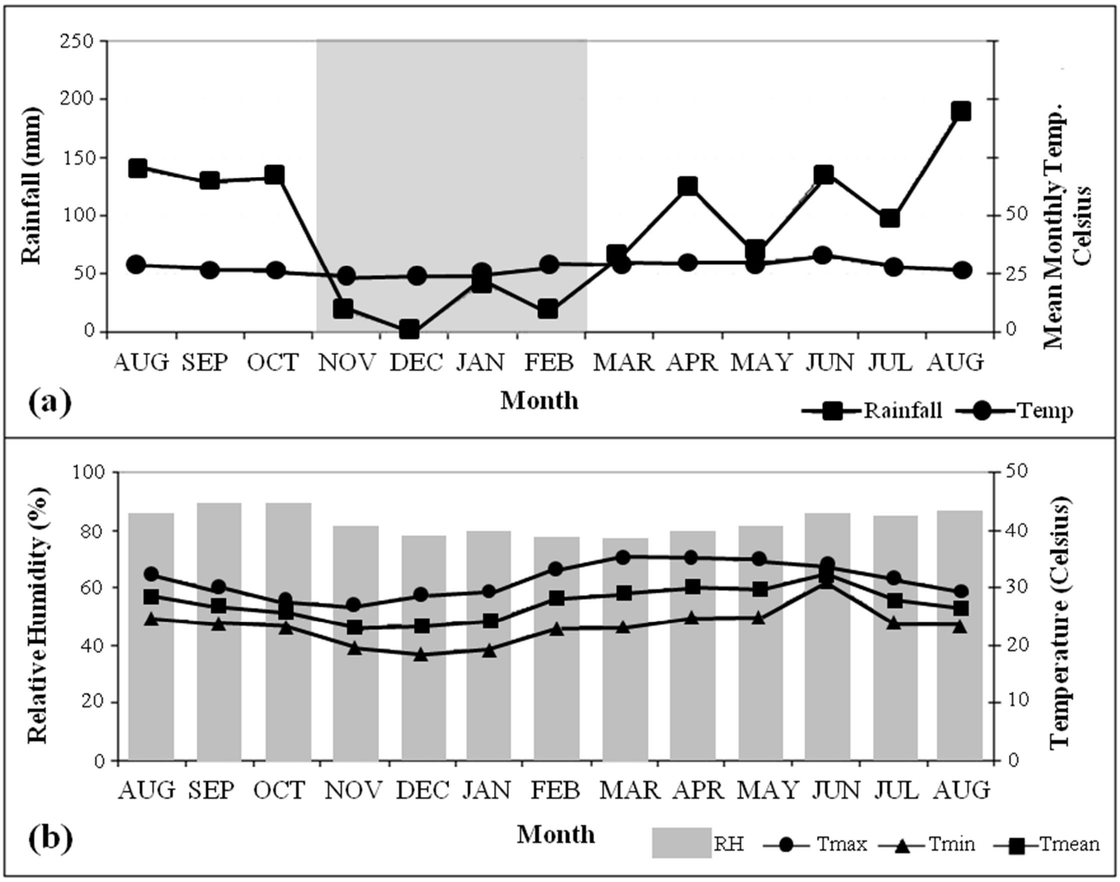

Figure 2: Meteorological data in August 2009 - August 2010; Rainfall and temperature data (a); Relative humdity and temperature data (b)

all marked points were extracted and wounded blocks were carefully polished using several grades of abrasive papers to obtain clean and smooth wood surfaces until marked wounds were prominently visible. The distances from the baseline (first marked point) to each monthly marked point was measured and calculated for monthly and total wood increments (Siripatanadilok, 1983) using the Velmex measuring system to the nearest 0.001 mm accuracy. Leaf phenological data and monthly wood increments of OBD and IBD were then correlated with monthly climatic data of rainfall, temperature, relative humidity and soil moisture contents using the multiple linear regression technique, namely path analysis (PA), to explain the effect of climate variability on tree growth in the lower canopy with multi-collinearity removal (Hu and Bentler, 1999; O'Brien, 2007).

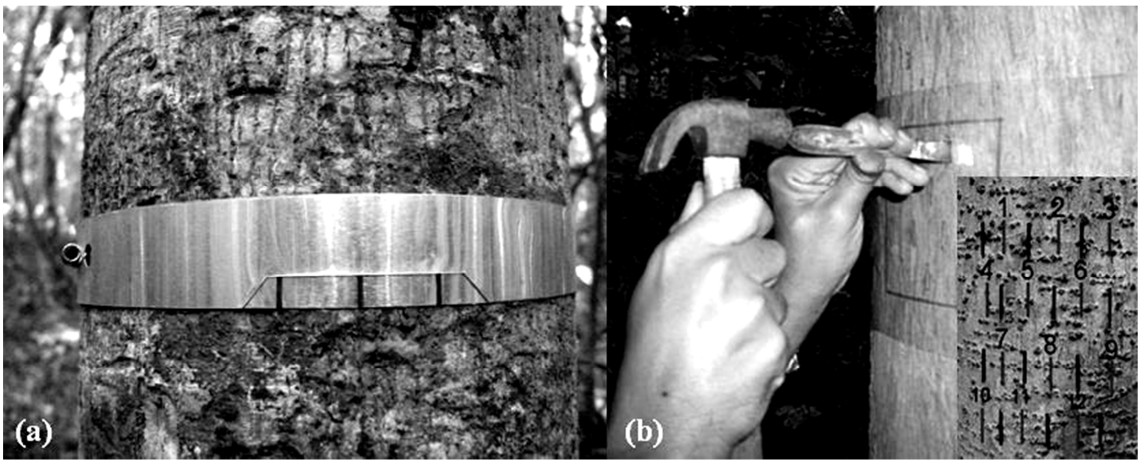

Figure 3: Manual band dendrometer installation (a) and cambial wounded marking (b)

3. Results

During the investigation period of one year, leaf phenology of 6 mature *Aglaia odoratissima* showed leaf flushing (LF) in August to November. Mature light green leaf (MLL) was commonly found associated with LF and abundant in April and May, which was the beginning of the rainy season. Mature dark green leaf (MDL) was abundantly found in every month, except in April and May which MLL abundantly found instead of other leaf pheno-phases. Leaf abscission (LA) was commonly found in dry period of December to March (Figure 4a). In case of 6 mature (Figure 4a).

In case of 6 mature *Hydnocarpus ilicifolia*, LF was not found during the investigated period. The small amounts of MLL were commonly found in May to August, while MDL were abundantly found in every month, especially in rainy season as similar as *A. odoratissima*. Small amounts of LA were commonly found throughout the investigation periods (Figure 4b).

Outside bark diameter (OBD) at breast height (130 cm) of all selected *A. odoratissima* and *H. ilicifolia* were monthly measured at the same time as leaf phenological investigation.

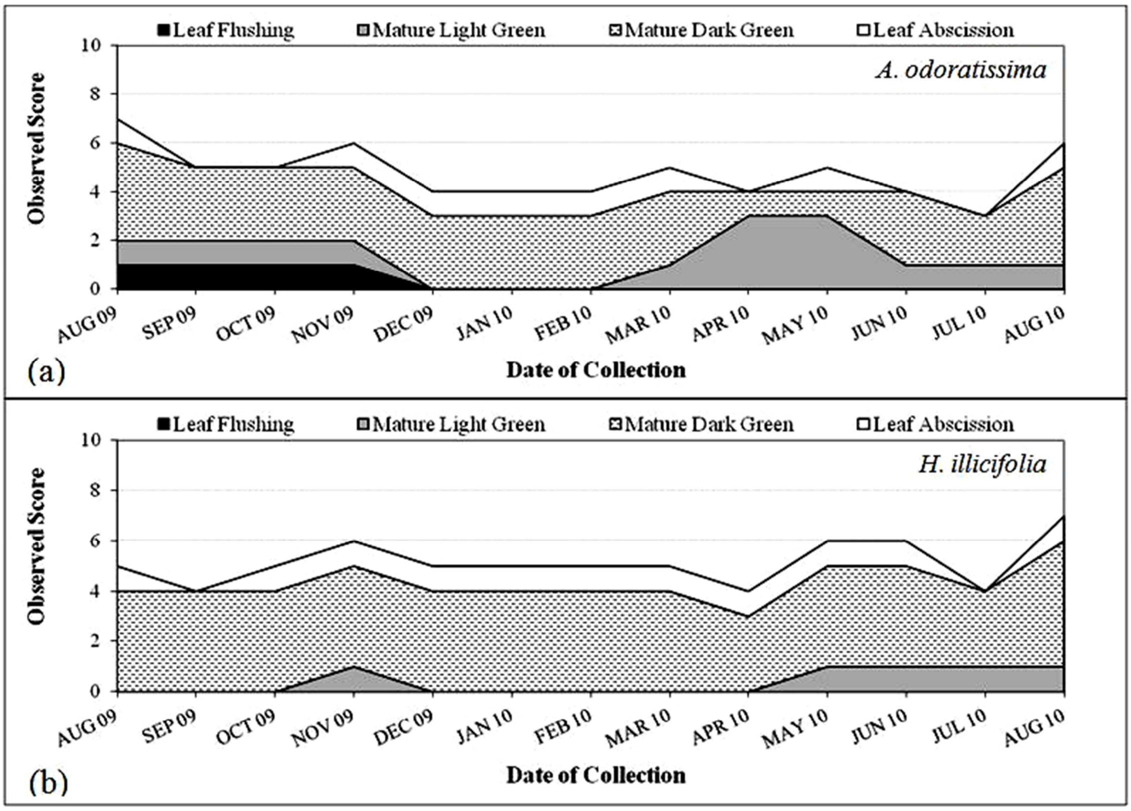

Figure 4: Leaf phenology of *A. odoratissima* (a) and *H. ilicifolia* (b)

Not only direct values of OBD, but standardized values of OBD increments were also calculated using z-score which was the value of the element (X) minus by the population mean ($\bar{X}$) and divided by the standard deviation (SD). If a z-score was positive or negative, it could interpret that the direct value was above (greater than) or below (less than) the mean, respectively. The z-score formula was shown as below.

$$z = \frac{X - \bar{X}}{SD} \qquad \textbf{(1)}$$

The cumulative OBD and standardized z-score profile of six *A. odoratissima* from August 2009 - September 2010 are shown in Figure 5a and 5b. During the investigated periods, the vernier scales of all installed band dendrometers were not changed for 5 months in September 2009 to January 2010,except *A. odoratissima* coded AO01 which OBD mildly increased by 0.07 mm.

The OBD of *A. odoratissima* rapidly shrank in February 2010 and gently increased in March - April 2010, unchanged in May-June 2010, and gently increased in July-September 2010. The cumulative diameters of all *A. odoratissima* were averaged, and the average increment was 0.024 cm/year.

Based on the cumulative OBD of six *H. ilicifolia*, as shown in Figure 6a and 6b, both direct value and standardized increment data exhibited dormant growth from September 2009

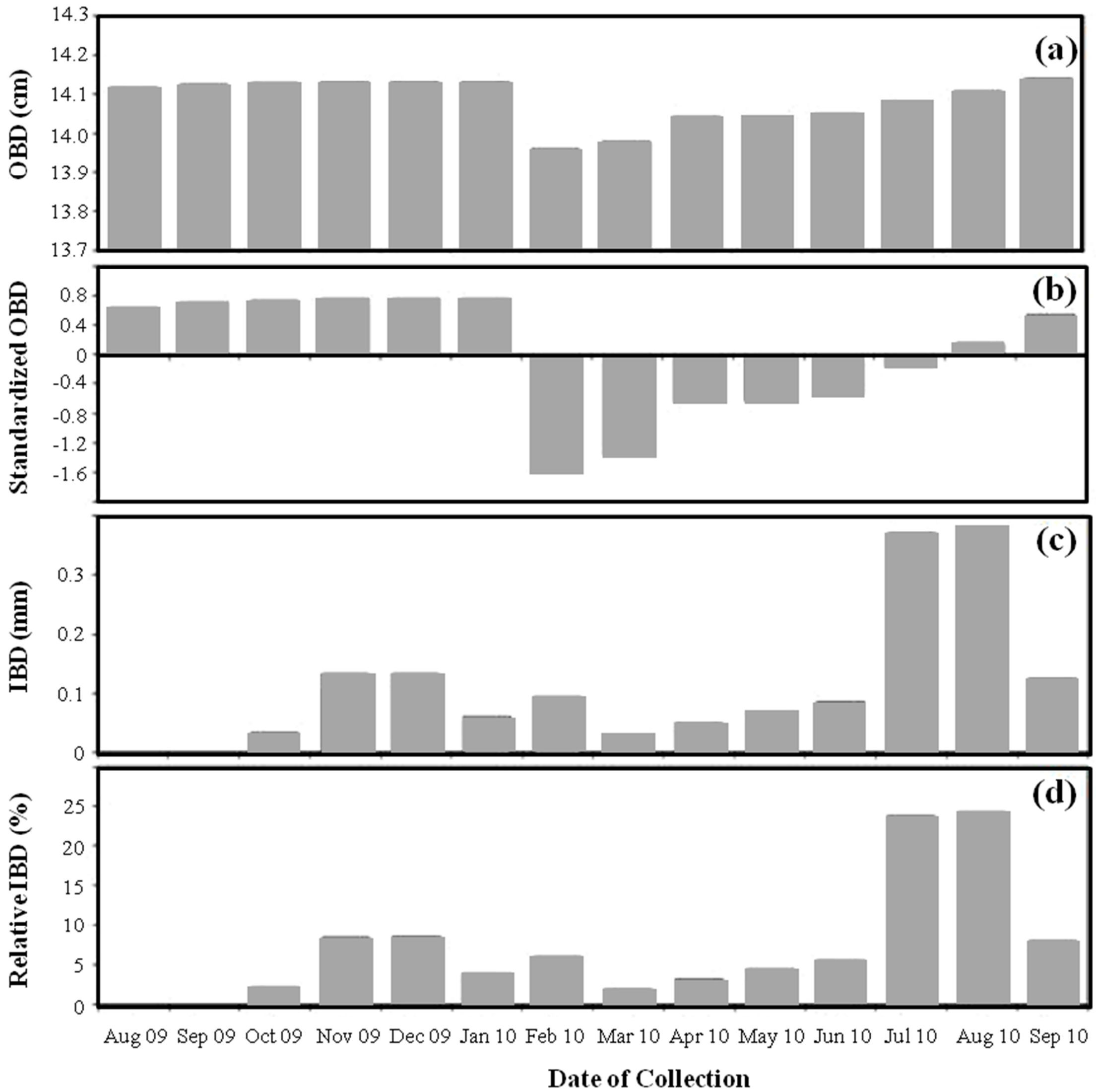

Figure 5: Outside (OBD) and inside bark diameter (IBD) increments of *A. odoratissima*

till January 2010 as similar as *A. odoratissima*. The OBD rapidly in May 2010 and gently increased until September 2010. However, the cumulative OBD of *H. ilicifolia* at the end of the investigation period was lower than the baseline data recorded in August 2009 of 0.045 cm.

Inside bark diameter (IBD) increment of *A. odoratissima* increased in August 2009 till September 2010; it averaged 1.56 mm (Figure 5c). The dormant period where monthly wood increment did not change was found to be in September 2009 after the cambial markings. However, it was difficult to identify this period as a stop in growth or dormant period of *A. odoratissima* due to the continuous occurrences of wood increment in September 2010.

Wood increment stopped in September 2009 and was re-stimulated in October 2009, averaging 0.03 mm (1.34% of total wood increment) and continuously increased to 0.13 mm (8.46%) in both of November and December 2009. Wood increment gradually declined and fluctuated from 0.03 till 0.09 mm in January till June 2010. Total wood increment in these six months was 0.39 mm (24.89% of overall increment). In July till September 2010, wood increment rapidly increased to 0.87 mm (55.97%). Although wood increment could be detected in every month during the investigated periods, the patterns of wood increments in all trees were not similar. It might be assumed that wood increments of *A. odoratissima* were not dependent on factors affecting tree growth, especially climatic factors. Wood increments continuously increased as shown in Figure 5c and 5d, which showed the fluctuation of directly measured and relative monthly wood increments of *A. odoratissima* during investigation periods.

During September 2009 till the September 2010, the OBD increment of *H. ilicifolia* decreased (Figure 6a and 6b), while the IBD increment increased to 1.03 mm (Figure 6c and 6d). After cambial marking at the beginning of September 2009, monthly IBD did not change for 3 months in September – November 2009, except a tree coded HI05 whose wood increment in November 2009 was 0.06 mm (4.31% from total growth of HI105). Unchanged wood increment in these 3 months seemed to be the document period of *H. ilicifolia* at SERS. The average of wood increments of *H. ilicifolia* trees, which started in December 2009 and continuously grew until February 2010, was 0.07 mm (5.59% of total growth). In April to June 2010, wood increment was 0.06 mm (5.29%). It could be stated that, after dormant periods, wood increment in December 2009 till June 2010 was very slow. In July to September 2020, wood growth rapidly increased to 0.89 mm (88.49%) and the rate of wood increment continuously increased. Figure 6c and 6d illustrate the variations of direct and relative monthly wood increments of *H. ilicifolia* during investigation periods.

In order to calculate effects of climate variability on tree growth, climatic (rainfall, Tmax, Tmean, Tmin, RH) and soil moisture (SM) variables were converted to 2 components of climatic data based on the criteria of Eigen values ≥ 1.

Based on varimax rotation of principle component analysis (Kaiser, 1958), the rotated component matrix of 2 non-significantly correlated components was observed. The first component was related to relative humidity, rainfall and soil moisture contents in all soil depths and was re-named as “Moisture”.

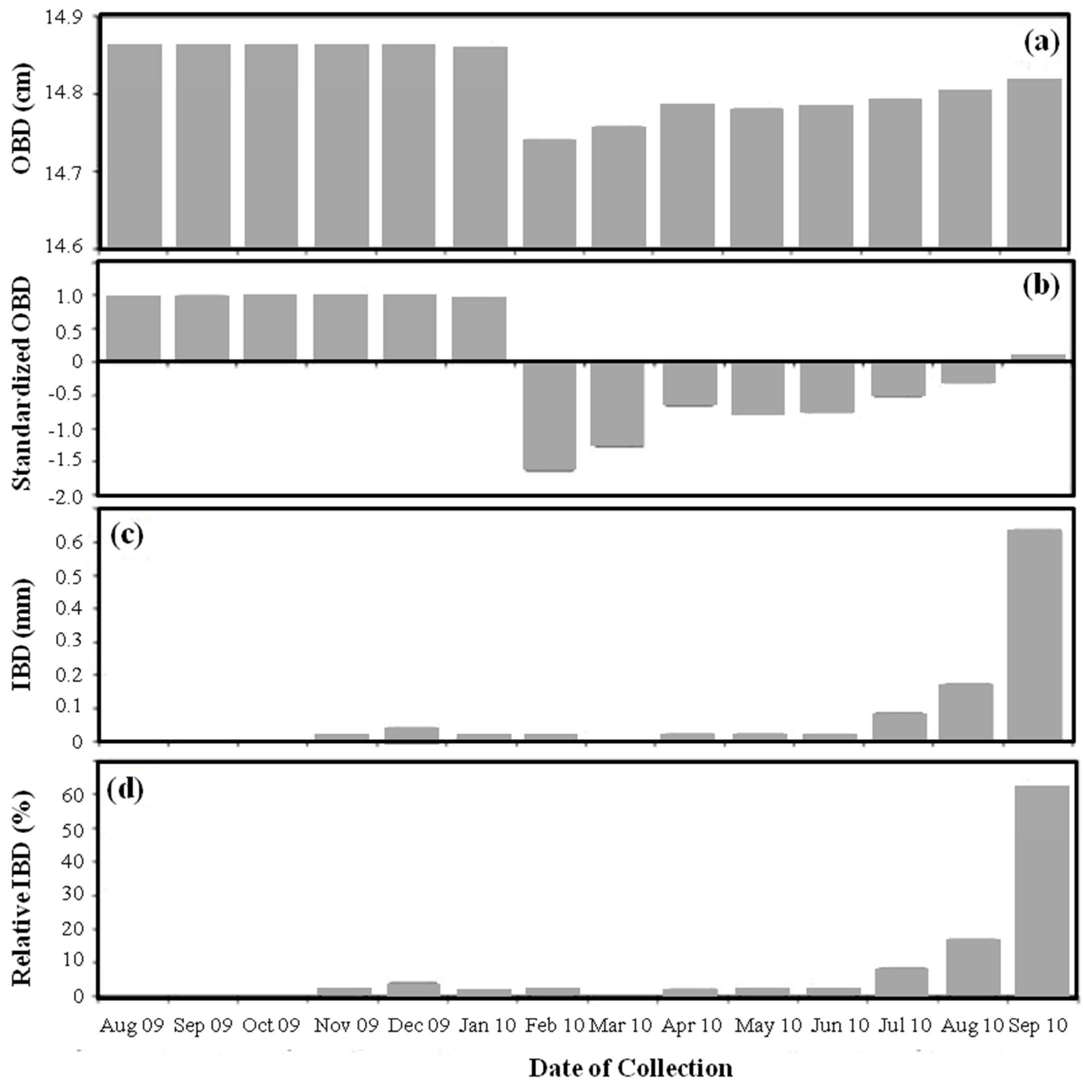

Figure 6: Outside (OBD) and inside bark diameter (IBD) increments of *H. ilicifolia*

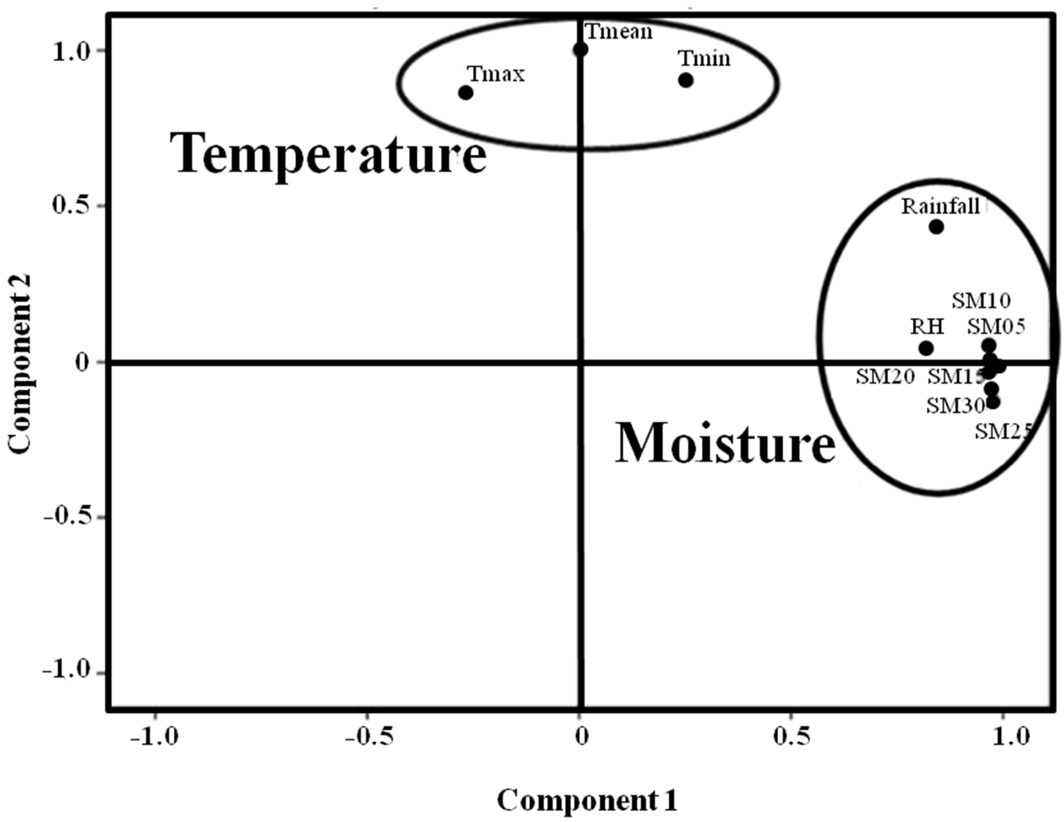

Figure 7: Grouping of SERS climatic and soil moisture variables into two components of "Temperature" and "Moisture" using principle components analysis

The second factor was related to Tmax, Tmin and Tmean and was re-named as "Temperature". These 2 components (Figure 7) were then used as independent factors in regression analysis and could explain all selected climatic data (90.83%).

As show in Figure 8, using path analysis with statistically significant p<0.05, temperature and moisture were the major climatic factors directly influencing mature dark green leaf (MDL) of *A. odoratissima* (r = -0.56) and leaf abscission (LA) (r = -0.58).

The occurrences of MDL and LA could be explained by the fluctuation of temperature and moisture for 31% and 34%, respectively.

Outside bark diameter increment detected by manual band dendrometers was induced by temperature (r = -0.74) and moisture (r = 0.40).

The association of temperature and moisture could explain the fluctuation of outside bark diameter of 71%. All climatic and phenological factors were not significantly related to monthly wood increment of *A. odoratissima*.

The testing of climate inducing leaf phenology and tree growth of *H. ilicifolia* using path analysis indicated that the model was fit and passed the overall model fit examination (χ^2 = 0.04, df = 2, p = 0.98; Root Mean Square Error of Approximation (RMSEA) = 0.00 and Comparative Fit Index (CFI) = 1.00).

Path coefficients, which are illustrated in Figure 9 were statistically significant (p<0.05).

All climatic factors were not significantly related to leaf phenology of *H. ilicifolia*, while IBD detected by cambial marked technique increased due to the fluctuation of moisture (r = 0.58).

Moisture could explain wood increment of *H. ilicifolia* (34%). The OBD detected by manual band dendrometers directly changed due to monthly wood increment (r = -0.45).

Not only monthly wood increments, but moisture and temperature also directly influenced wood increment (r = 0.50 and -0.78, respectively). Moisture also had an indirect effect on OBD increment through monthly wood increment (r = -0.26).

Moisture, temperature and monthly wood increment could explain the fluctuation of outside bark diameter increment of 79%. Overall, moisture was the most important factor affecting monthly wood increment (r = 0.58). The OBD increment was mainly induced by temperature (r = -0.78) followed by IBD (r = -0.45) and moisture (r = 0.24).

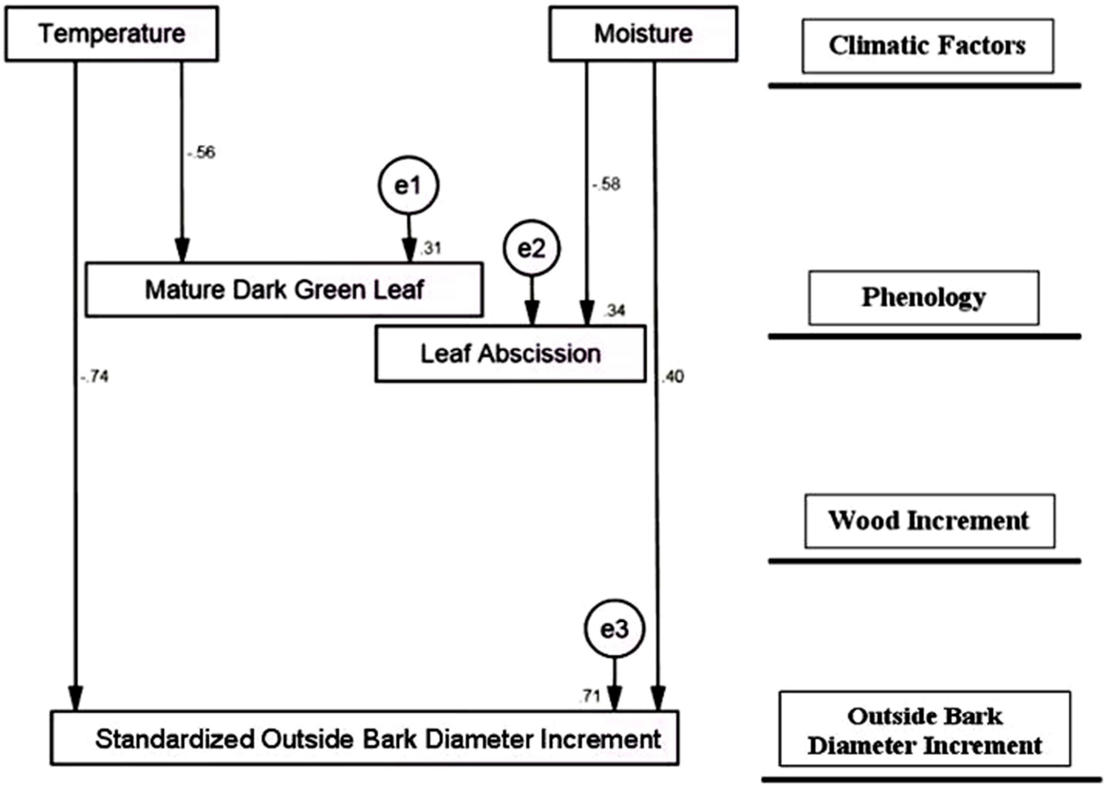

Figure 8: Path diagrams: factors affecting tree growth of *A. odoratissima* and e1, e2 and e3 indicated errors in predicting the values of mature dark green leaf, leaf abscission and standardized outside bark diameter increment, respectively

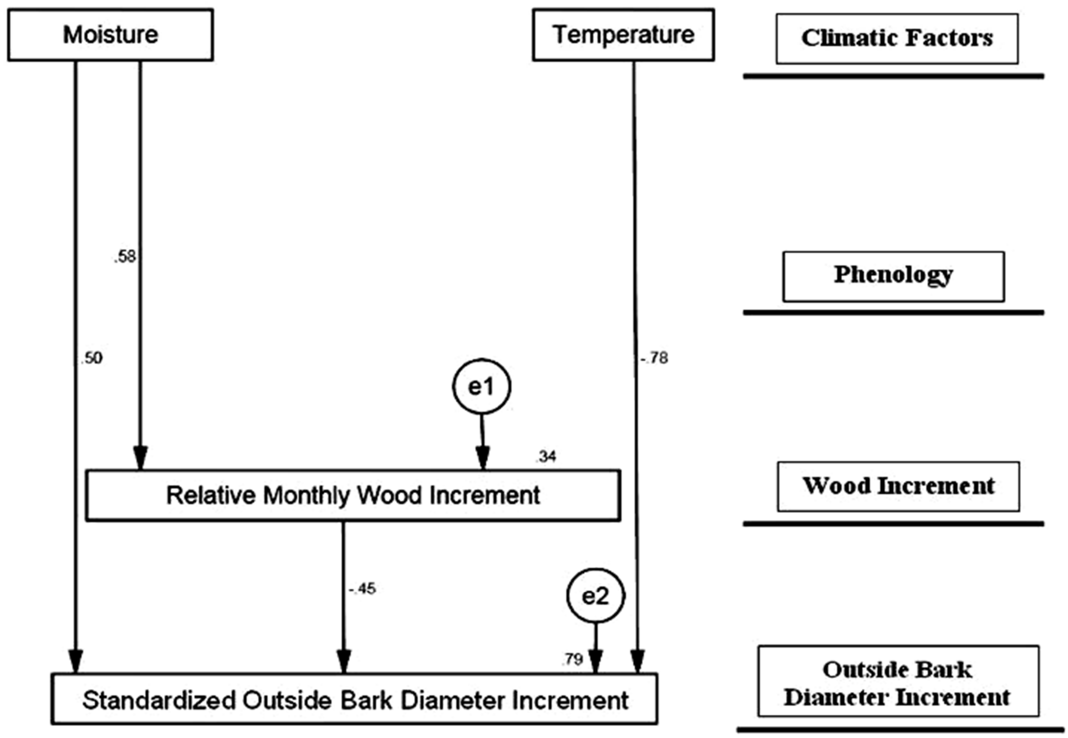

Figure 9: Path diagrams: factors affecting tree growth of *H. ilicifolia* and e1 and e2 indicated errors in predicting the values of relative monthly wood increment, and standardized outside bark diameter increment, respectively.

4. Discussion

Based on leaf phenology, *A. odoratissima* and *H. ilicifolia* produced abundant leaf crowns throughout the year, especially in the rainy season (Gutierrez-Soto, 2008). Young leaves were abundantly found in rainy season and leaf abscission rarely found throughout the year. Xiao et al. (2006) suggested that leaf pheno-phases of evergreen trees in the tropics were not related to the seasonality of rainfall. Instead, the fluctuation of leaf phenology may be forced by solar radiation availability. Williams et al. (2008) studied leaf phenology of *A. odorata* and *A. spectabilis* growing in western Thailand and also found the evergreen and leaf flushed characteristics at the beginning of the rainy season.

The increments of OBD in *A. odoratissima* and *H. ilicifolia* continuously declined from the installed period in the second half of the rainy season to the end of the dry season (September 2009 - February 2010). In the rainy season, OBD rapidly increased from March 2010 until the end of the investigated period in September 2010. *A. odoratissima* and *H. ilicifolia* showed fast increment at the beginning of the rainy season but illustrated the unchanged OBD at the end of the rainy season and the dry season. The extreme shrinkage of OBD occurred for one month in February before rainfall in March. The OBD showed extreme shrinkage in February before diameter increment gently increased in March. Therefore, the suitable period of band dendrometer installation for tree growth measurement at SERS should be during the transition of dry and wet periods at the end of February. Pelissier and Pascal (2000) stated that OBD variations originated from hydrostatic force inducing stem flexibility which depended on the degree of turgidity or water stress of the tree. It was similar to the study of radial stem variations of several tree species relating water status including precipitation and vapor pressure deficit (Bräuning and Burchardt, 2005; Lisi et al., 2008; Oberhuber and Gruber, 2010; Volland-Voigt et al., 2011).

As dendrometer bands were installed over bark in order to continue the measurement of tree growth, changes in phloem differentiation and bark width relating to total OBD increment was important to understand. Several authors suggested that the swelling and the shrinkage in stems mostly occurred in bark, phloem and the zone of cambium, while variation in xylem zone was insignificantly related (Brough et al., 1986; Daudet et al., 2005; Dobbs and Scott, 1971; Molz and Klepper, 1973; Zweifel et al., 2000). The OBD variation in *Eucalyptus nitens*, approximately 40%, had been attributed to shrinkage of phloem and bark (Downes et al., 1999). This information must be taken in to consideration, when analyzing and interpreting the OBD data

Monthly wood increments of *A. odoratissima* and *H. ilicifolia* derived from cambial marking studies were found throughout the year as similar as leaf phenology. Growth rates of these species rapidly increased and maximized in the rainy season. Several authors claimed that lower rainfall during the winter strongly reduced wood increment, while wet condition during the rainy season induced wood increment in both of broad leaf and long leaf trees (Lisi et al., 2008; Marcati et al., 2006 and 2008; Singh and Venugopal, 2011). There were few investigations on wood formation in evergreen tree species such as Sass et al. (1995) who found a continuous process in wood formation of *Dryobalanops sumatrensis* and *Shorea leprosula*, which was not related to seasonality in rainfall and phenology.

Based on the occurrences and abundances of leaf phenology, monthly wood increments of these evergreen species was not significantly related to the occurrences of their leaves, results similar to those of the study of O'Brien et al. (2008).

All climatic data did not showed the significant correlation with the monthly wood increment of *A. odoratissima* but moisture was significantly related to wood increment of *H. ilicifolia*. Lamotte et al. (1998) and Marod et al. (2003) explained that *H. ilicifolia* were co-dominant tree species and *A. odoratissima* were the lower layers of crown covers and were suppressed by other trees. Microclimatic factors varied vertically within the forest stand and induced plant water status changing vertically. Response to increased air temperature, higher leaf temperature in the upper canopy caused a steeper gradient of vapor pressure from the leaf to the air greater than the observation from the shaded understory and ground vegetation (Thompson and Hinckley, 1977). Therefore, the fluctuation of climate could directly affect these dominant and co-dominant tree species and explained the insignificant correlation or the lower effects to the suppressed or understory trees. However, Borchert (1999) explained that seasonal rainfall drove leaf phenology, cambial growth and wood increment in deciduous trees, but were progressively uncoupled in evergreen trees. Lisi et al. (2008) also found trunk increment dynamics of many tree spices in a seasonal semi-deciduous forest of Brazil corresponded to seasonal changes in precipitation.

Increments of *A. odoratissima* and *H. ilicifolia* OBD did not show the positive relationship with IBD increments. Depending on the stem shrink and swelling, increased or decreased temperature, respectively, induced shrinkage or swelling of OBD and moisture showed direct and positive effects on OBD increments. Several studies explained OBD increments in rainy or wet season related to new cell formation and development, while swelling and shrinkage in dormant period probably depended on the water content in bark, rather than changes in wood increment (Bräuning and Burchardt, 2005; Bräuning et al., 2008;

Deslauriers et al., 2003; Gruber et al., 2009; Jezik et al., 2007). However, to avoid the effect of bark swelling and shrinkage, several studies recommended the cambial wounding technique to investigate the seasonal rhythms of xylem growth instead of dendrometer bands (Kuroda and Kiyono, 1997; Makinen et al., 2008).

The study of IBD increments for one year was design to measure exact wood increment responding to monthly and seasonal climate variability. It could not refer to the long-term association of tree growth and climate change. The measurement of OBD increment using a modified manual band dendrometer is appropriated to study long-term periodic growth of indistinct and absent annual ring species which errors from bark characteristics are acceptable (Keeland and Sharitz, 1993; Schongart et al., 2002).

5. Conclusions

Two species of the evergreen trees, including *Aglaia odoratissima* and *Hydnocarpus ilicifolia*, were selected to study effects of monthly climate variability on monthly tree growth for a year. For leaf phenological studies, these selected trees illustrated leaf maturation throughout the year, while young leaves were abundantly found in rainy season, and leaf abscission rarely found throughout the year. The increments of outside bark diameters (OBD) of *A. odoratissima* and *H. ilicifolia* continuously decreased from the installation period in the second half of rainy season to the end of dry season, and rapidly increased at the beginning of the rainy season until the end of the investigation d period; the inside bark diameter (IBD) increments of both species showed the dormancy period in the dry season.

The climatic factors of moisture and temperature components derived from the Principle Component Analysis (PCA) showed both direct and indirect effects on monthly wood increments. The increased moisture directly induced IBD increments of *H. ilicifolia*, but these two climatic components did not show a significant relationship with IBD of *A. odoratissima*. Using the technique of path analysis (PA), the fluctuation of leaf phenology of these two species was not significantly related to the increments of IBD. The OBD increments of *H. ilicifolia* were directly and positively related to the increment of IBD, while *A. odoratisima* OBD was not significantly correlated with IBD. Depending on the shrink and swelling of OBD increments, *A. odoratissima* OBD was directly related to moisture and temperature components, and *H. ilicifolia* OBD showed both direct and indirect relationships to the fluctuation of all the climatic components.

For further studies, *A. odoratissima* and *H. ilicifolia* growing in the different sites shall be studied to confirm the finding of this research as similar as the study of long-term periodic growth for climate change investigation. Several researches suggested that photoperiod involved photosynthesis, tree growth, and phenological changes (Basler and Korner, 2014; Jackson, 2009). Its relationship with tree growth shall be in-depth studies in the next step. Other tree species in the lower canopy shall also be applied to analyze climate-growth relationship and the weather station shall be installed to collect the local climatic data in each selected forest stand.

6. Acknowledgements

The project was partly funded by a grant from the Center for Advanced Studies in Tropical Natural Resources (CASTNR) under the National Research University-Kasetsart University (NRU-KU).

7. References

Andreu, L., Gutierrez, E., Macias, M., Ribas, M., Bosch, O. and Camarero, J.J. 2007.Climate increases regional tree-growth variability in Iberian pine forests. **Global Change Biology** 13: 804–815.

Basler, D. and Korner, C. 2014. Photoperiod and temperature responses of bud swelling and bud burst in four temperate forest tree species. **Tree Physiology** 34: 377-388.

Borchert, R. 1999. Climatic periodicity, phenology, and cambial activity in tropical dry forest trees. **IAWA Journal** 20(3): 239-247.

Brough, D.W., Jones, H.G. and Grace, J. 1986. Diurnal changes in water content of the stems of apple trees, as influenced by irrigation. **Plant, Cell & Environment** 9: 1–7.

Bräuning, A., Homeier, J., Cueva, E., Beck, E. and Gunter, S. 2008. Growth dynamics of trees in tropical mountain ecosystems. **Ecological Studies** 198: 291-302.

Bräuning, A. and Burchardt, I. 2005.Detection of growth dynamics in tree species of a tropical mountain rain forest in southern Ecuador. In: **TRACE – Tree Rings in Archaeology, Climatology and Ecology, vol. 4** (pp. 127-131).Proceedings of the DENDROSYM POSIUM 2005. Fribourg: Switzerland.

Buckley, B.M., Barbetti, M., Wattanasak, M., D’Arrigo, R., Boonchirdchoo, S. and Sarutanon, S. 1995.Dendrochronological investigations in Thailand. **IAWA Journal** 16(4): 393-409.

Daudet, F., Ameglio, T., Cochard, H., Archilla, O. and Lacointe, A. 2005. Experimental analysis of the role of water and carbon in tree stem diameter fluctuations. **Journal of Experimental Botany** 56: 135-144.

Deslauriers, A., Morin, H., Urbinati, C. and Carrer, M. 2003. Daily weather response of balsam fir (*Abies balsamea* (L.) Mill.) stem radius increment from dendrometer analysis in the boreal forests of Québec (Canada). **Trees** 17: 477–484.

Dobbs, R.C. and Scott, D.R.M. 1971. Distribution of diurnal fluctuations in stem circumference of Douglas fir. **Canadian Journal of Forest Research** 1: 80–83.

Downes, G.M., Beadle, C., Gensler, W., Mummery, D. and Worledge, D. 1999. Diurnal variation and radial growth of stems in young plantation eucalypts. In: **Tree Ring Analysis** (pp. 83–104). Biological, Methodological and Environmental Aspects. New York: CAB Inter- National.

D'Arrigo, R.D., Barbetti, M., Wattanasak, M., Buckley, B., Krusic, P., Boonchirdchoo, S. and Sarutanon, S. 1997. Progress in dendroclimatic studies of mountain pine in northern Thailand. **IAWA Journal** 18(4): 433-444.

Fritts, H.C. 1976. **Tree Ring and Climate**. New York: Academic Press.

Garcia-Suarez, A.M., Butler, C.J. and Baillie, M.G.L. 2009. Climate signal in tree-ring chronologies in a temperate climate: a multi-species approach. **Dendrochronolo gia** 27: 183–198.

Gruber, A., Zimmermann, J., Wieser, G. and Oberhuber, W. 2009. Effects of climate variables on intra-annual stem radial increment in *Pinus cembra* (L.) along the alpine treeline ecotone. **Annals of Forest Science** 66(5):DOI:0.1051/forest/2009038.

Gutierrez-Soto, M.V., Pacheco, A. and Holbrook, N.M. 2008. Leaf age and the timing of leaf abscission in two tropical dry forest trees. **Trees** 22: 393-401.

Hu, L. and Bentler, P. M. 1999. Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. **Structural Equation Modeling** 6(1): 1-55.

Jackson, S.D. 2009. Plant responses to photoperiod. **New Phytologist**181: 517-531.

Jezik, M., Blazenec, M. and Strelcova, K. 2007. Intraseasonal stem circumference oscillations: their connection to weather course. In: **Bioclimatology and Natural Hazards** (pp. 1-10). International Scientific Conference. Pol'ana nad Detvou, Slovakia.

Kaiser, H.F. 1958. The varimax criterion for analytic rotation in factor analysis. **Psychometrika** 23(3): doi10.1007/ BF02289233.

Keeland, B.D. and Sharitz, R.R. 1993. Accuracy of tree growth measurements using dendrometer bands. **Canadian Journal of Forest Research** 23:2454-2457.

Kuroda, K. and Kiyono, Y. 1997. Seasonal rhythms of xylem growth measured by the wounding method and with band-dendrometer: an instance of *Chamaecyparis obtuse*. **IAWA Journal** 18(3): 291-299.

Lamotte, S., Gajaseni, J. and Malaisse, F. 1998. Structure diversity in three forest types of north-eastern Thailand (Sakaerat Reserve, Pak Tong Chai). **Biotechnology, Agronomy, Society and Environment** 2(3): 192-202.

Lisi, C.S., Tomazello, M., Botoss, P.C., Roig, F.A., Maria, V.R.B., Ferreira-Fedele, L. and Voigt, A.R.A. 2008. Tree-ring formation, radial increment periodicity, and phenology of tree species from a seasonal semi-deciduous forest in southeast Brazil. **IAWA Journal** 29: 189-207.

Makinen, H., Seo, J., Nojd, P., Schmitt, U. and Jalkanen, R. 2008. Seasonal dynamics of wood formation: a comparison between pinning, microcoring and dendrometer measurement. **European Journal of Forest Research** 127: 235-245.

Marcati, C.R., Oliveira, J.S. and Machado, S.R. 2006. Growth rings in Cerrado woody species: occurrence and anatomical markers. **Biota Neotropica** 6(3): 1-31.

Marcati, C.R., Milanez, C.R.D. and Machado, S.R. 2008. Seasonal development of secondary xylem and phloem in *Schizolobium parahyba* (Vell.) Blake (Leguminosae: Caesalpinioideae). **Trees** 22: 3-12.

Marod, D., Sangkaew, S. and Niamrat, W. 2003. The invasion of climax species into forest plantation. **Thai Journal of Forestry** 22: 1-15 (in Thai).

Molz, F.J. and Klepper, B. 1973. On the mechanism of water- stress-induced stem deformation. **Agronomy Journal** 65: 304–306.

Nitschke, C.R. and Innes, J.L. 2008. A tree and climate assessment tool for modeling ecosystem response to climate change. **Ecological modeling** 210: 263–277.

Oberhuber, W. and Gruber, A. 2010. Climatic influences on intra-annual stem radial increment of *Pinus sylvestris* (L.) exposed to drought. **Trees** 24: 887-898.

O'Brien, R.M. 2007. A caution regarding rules of thumb for variance inflation factors. **Quality and Quantity** 41(5): 673-690.

O'Brien, J.J., Oberbauer, S.F., Clark, D.B. and Clark, D.A. 2008. Phenology and stem diameter increment seasonality in a Costa Rican wet tropical forest. **BIOTROPICA** 40(2): 151-159.

Pelissier, R. and Pascal, J. 2000. Two-year tree growth patterns investigated from monthly girth records using dendrometer bands in a wet evergreen forest in India. **Journal of Tropical Ecology** 16: 429-446.

Polgar, C.A. and Primack, R.B. 2011. Leaf-out phenology of temperate woody plants: from trees to ecosystems. **New Phytologist** 191: 926–941.

Pumijumnong, N. and Eckstein, D. 2011. Reconstruction of pre-monsoon weather conditions in northwestern Thailand from the tree-ring widths of *Pinus merkusii* and *Pinus kesiya*. **Trees** 25: 125-132.

Pumijumnong, N., Eckstein, D. and Sass, U. 1995. Tree-ring research on *Tectona grandis*in northern Thailand. **IAWA Journal** 16(4): 385-392.

Pumijumnong, N. and Wanyaphet, T. 2006. Seasonal cambial activity and tree-ring formation of *Pinus merkusii* and *Pinus kesiya* in Northern Thailand in dependence on climate. **Forest Ecology and Management** 226(1): 279-289.

Sass, U., Killmann, W. and Eckstein, D. 1995. Wood formation in two species of Dipterocarpaceae in peninsular Malaysia. **IAWA Journal** 16(4): 371-384.

Schongart, J., Piedade, M.T.F., Ludwigshausen, S., Horna, V. and Worbes, M. 2002. Phenology and stem-growth periodicity of tree species in Amazonian floodplain forests. **Journal of Tropical Ecology** 18:581-597.

Singh, N.D. and Venugopal, N. 2011. Cambial activity and annual rhythm of xylem production of *Pinus kesiya* Royle ex. Gordon (Pinaceae) in relation to phenology and climatic factors growing in sub-tropical wet forest of North East India. **Flora** 206: 198-204.

Siripatanadilok, S. 1983. **Plant Microtechniques**. Bangkok: Faculty of Forestry, Kasetsart University (in Thai).

Thompson, D.R. and Hinckley, T.M. 1977. Effect of vertical and temporal variations in stand microclimate and soil moisture on water status of several species in an Oak-Hickory forest. **American Midland Naturalist** 97(2): 373-380.

Thompson, O.E. and Landsberg, H.E. 1975. Climatological conditions in the Sakaerat forest, Thailand. **Physical Geography** 57(3): 247-260.

Trouet, V., Diaz, H.F., Wahl, E.R., Viau, A.E., Graham, R., Graham, N. and Cook, E.R. 2013. A 1500-year reconstruction of annual mean temperature for temperate North America on decadal-to-multidecadal time scales. **Environmental Research Letters** 8:1-10.

Vitasse, Y., Delzon, S., Dufrene, E., Pontailler, J.Y., Louvet, J.M., Kremer, A. and Michalet, R. 2009. Leaf phenology sensitivity to temperature in European trees: do within-species populations exhibit similar responses. **Agricultural and Forest Meteorology** 149: 735-744.

Volland-Voigt, F., Brauning, A., Ganzhi, O., Peters, T. and Maza, H. 2011. Radial stem variations of *Tabebuia chrysantha* (Bignoniaceae) in different tropical forest ecosystems of southern Ecuador. **Trees** 25: 39-48.

Williams, L.J., Bunyavejchewin, S. and Baker, P.J. 2008. Deciduousness in a seasonal tropical forest in western Thailand: interannual and intraspecific variation in timing, duration and environmental cues. **Oecologia** 155: 571-582.

Xiao, X., Hagen, S., Zhang, Q., Keller, M. and Moore, B. 2006. Detecting leaf phenology of seasonally moist tropical forests in South America with multitemporal MODIS images. **Remote Sensing of Environment** 103: 465-473.

Zweifel, R.,Item, H. and Hasler, R. 2000. Stem radius changes and their relation to stored water in stems of young Norway spruce trees. **Trees** 15: 50–57.