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Dendrochronology of young *Swietenia macrophylla* and the variation of its growth response to the past wet climate in Bengkulu, Indonesia

AGUS SUSATYA[1,♥], **YANSEN**[2]
[1]Department of Forestry, Universitas Bengkulu. Jl. WR Supratman, Kandang Limun Bengkulu 38371, Bengkulu, Indonesia. Telp +62 736 21170. ♥email: satya1812@yahoo.com
[2]Department of Forestry, Universitas Bengkulu. Jl. WR Supratman, Kandang Limun Bengkulu 38371, Bengkulu, Indonesia.

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Abstract. *Susatya A, Yansen. 2016. Dendrochronology of young* Swietenia macrophylla *and the variation of its growth response to the past wet climate in Bengkulu, Indonesia. Biodiversitas 17: 466-472.* Dendrochronology had long been studied in temperate regions to know tree growth responses to the past climate, and to predict the future effects of climate change. In the wet tropics, dendrochronology studies were rarely carried out because of the lack of distinct annual growth rings or wide variation of growth ring forms. Our research was aimed to know the variations of width of growth rings, and growth response of young Big-Leaf Mahogany (*Swietenia macrophylla*) to the past wet climate in Bengkulu, Indonesia. Wood disc specimens of cross sections were collected from seven different mahogany trees from campus forest, University of Bengkulu, and then were dried, sanded, and digitally photographed. Growth rings were measured to the nearest 0.001 cm with ImageJ software. The annual ring width data were cross-dated visually by synchronizing and aligning the width patterns of all wood specimens. The results showed that the average of annual growth rings varied from 0.679 cm/year to 1.047 cm/year, and was not significantly different among trees. The width of growth ring of Big-Leaf Mahogany trees demonstrated periodicity through ages, and increased until 9 years old and then started to decline. Individual tree responded differently to climate through out the ages. In the stand level, the average annual growth ring was very sensitive to climate, and positively correlated to rainfall in the first six years, but was independent to rainfall in the past five years. It was speculated that local environments and ecological processes were attributed to obscure the influence of rainfall to the annual growth ring of the older stand.

Keywords: Annual growth ring, cross date, dendrochronology, Indonesia, tropics

INTRODUCTION

Mitigation and adaptation for climate change rely on the health of ecosystems. In many aspects, species compositions of forests will determine the end result of mitigation, because the species will control the total carbon sequestered and balance to the ecosystems. Carbon sequestration capability can be reflected by the variation of annual growth rings of trees (Fritts and Swetnam 1989; Sesler 2009). These growth rings are results from the distinct differences between cell division of vascular tissues at growing and dormant seasons. The sequence of annual growth rings within trees is then studied by dendrochronology (Norton and Ogden 1987). The core of dendrochronology is cross dating, which is referred as a method to conduct comparisons and synchronizations the similarity of the width patterns of the annual growth ring of the different trees, and then to relate the patterns to ages (Fritts and Swetnam 1989; Laroque 1995). This method is based on the assumption that climate will similarly affect the growth of all trees in a given area, and therefore, the trees will produce similar patterns of the growth rings (Norton and Ogden 1987; Boninsegna et al. 2009). Dendrochronology is widely used to understand the relationship between radial growth and past environment, past climate and hydrological regimes (Fritts and Swetnam 1989; Fritts and Dean 1992), forest community changes through time (Guindon and Kit 2012), and species' responses to climate change (Ettl 1994; Guindon and Kit 2012). Dendrochronology studies also allow reconstruction of past climates (Martinelli 2004; Sano et al. 2008; Boninsegna et al. 2009; D'Arrigo et al. 2011; Pumijumnong 2012b), and estimations for carbon sequestration (Bascrietto et al. 2004; Martinelli 2004). For example, Fritts and Dean (1992) analyzed wood cores of Pines to estimate past climates between the years of 900 to 1200, and summarized that the very dry spring and summer of mid-1100 caused the distinctive variation of growth rings in Southwest USA. A similar pattern was also reported by Lopez et al. (2012), where the presence of annual rings in seven tree species of tropical moist forests was the result of dry months. A strong correlation between past climates with growth rings was also shown by *Arbutus menziesii* (Ettl 1994), teak, *Tectona grandis* (Stahle 1999; Worbes 2002), and *Nothofagus pumilio* and *Polylepis tarapacana* (Boninsegna et al. 2009). However, climate was not the only factor influencing the variation of growth rings. The ring width variation within a single tree of *Pinus merkusii* and *P. kesiya* was more influenced by local soil moisture than by rainfall as well as temperature (Pumijumnong and Wanyaphet 2006). The ring widths of *Abies lasiocarpa* were also known to have a weak correlation with regional climate, but to perform a strong sensitive to microclimate (Guindon and Kit 2012).

In the contrary to temperate regions, where dendrochronology has been extensively studied (Norton and Ogdnen 1987; Fritts and Dean 1992; Martinelli 2004; Guindon and Kit 2012), dendrochronology has been practiced less in the tropics, even though some early works in the tropics can be traced back to the early 1900s, when Dutch scientists carried out a study in Java, Indonesia (Worbes 2002). Because of increasing role of forest in mitigating effects of climate change and of the need for information of the relationship between tree growth and climate, dendrochronology has been growingly conducted in various tropical regions such as South America (Worbes 2002; Boninsegna et al. 2009), Tibet (Liang and Eckstien 2009), Ethiopia (Wils et al. 2010), and Eastern Guatemala (Sigal 2011). In South East Asia region, dendrochronology and its various techniques were also gaining attention (Pumijumnong 2012a). For example, D'Arrigo et al. (2006) used wood rings data from 9 living teak to understand drought monsoon variation in the past two centuries in Java Indonesia. Sono et al. (2008) utilized the growth rings of *Fokienia hodginsii* to reconstruct the eighteenth century climate in Northern Vietnam. D'Arrigo et al. (2011) used growth rings from 20 living teaks to study the past three centuries monsoon variability in Myanmar. Furthermore, Pumijumnong and Wanyaphet (2006) and Pumijumnong (2012b) also explored Teak and two species of Pinus to study past climate in Northern Thailand. Unfortunately, dendrochronology in South East Asia was limitedly conducted based on data from very few tree species. Pumijumnong (2012a) listed only 4 tree species consisting of *Pinus merkusii, P. kesiya, Tectona grandis,* and *Fokienia hodginsii* that showed responsive to past climate. In such a high tree species diversity of Sumatra rain forest (Susatya 2010), information on the response of growth of the other species to climate is necessary to gain a better understand the role past and future climates to the ecosystem.

In the wet tropics, people reluctantly explored dendrochronology to study past climatic and ecological events related to annual growth rings. This was partly caused by reasons that the growth rings of trees were not distinctively formed, the annual variation of climate was not strong enough to form distinct rings in the wet tropics (Lopez et al. 2012), and that false, incomplete, poorly defined or multiple rings were abundant (Wils et al. 2010; Azim and Okada 2014). However, Baguinon et al. (2008) found interesting results concerning to the distinctiveness of growth rings of Southeast Asia trees. Baguinon et al. (2008) conducted a comprehensive study to determine growth rings of trees from various forest formations including wet tropical forests from Sri Lanka, India, Thailand, Malaysia, and The Philippines. They reported that of 424 tree species, ninety-eight (23%) showed distinct rings, while the rest had either indistinct or missing rings. A similar study was also conducted in Peninsular Malaysia by Azim and Okada (2014). They reported that among 29 trees observed, only two tree species showed distinct growth rings, the other trees had either absence or poorly defined growth rings.

Big-leaf Mahogany, *Swietenia macrophylla* King, occurs through out the tropics of Asia, Central and South America, and is able to thrive in many soil types from very poor to well-drained and fertile in dry as well as wet tropical regions (Krisnawati et al. 2011). Distinct growth rings have been reported for this species (Baguinon et al. 2008), and therefore can be explored as a model to determine the various influence of the past climate to growth of species in the wet tropics. The objective of this research was to know the variation of the width of tree rings, and the growth response of young Big-Leaf Mahogany to climate and rainfall in the wet climate of Bengkulu, Sumatra, Indonesia.

MATERIALS AND METHODS

The study area was located in the campus forest of the University of Bengkulu in Bengkulu, Indonesia (3°45'30"S -102°16'22"E). The forest was a remnant of young secondary lowland rain forest, with its main tree species consisted of *Cinnamomum iners*, *Alstonia scholaris, Rhodamnia cinerea, Cassia siamea, Peronema canescens, Oroxylum indicum,* and *Vitex pinnata.* Other species associated with disturbance such as *Croton argyratus,* and *Endospermum diadenum* were also present. *Swietenia macrophylla* along with *Paraserianthes falcataria,* and *Shorea leprosula* was part of enrichment program planted during the early 2000 to 2008. Topography of the site was varied from gently to moderately sloping.

The site had wet climate, where over the past 10 years, the average annual rainfall in this area was 2620 mm with the maximum and minimum annual rainfalls reached 3750 mm (2005) and 2286 mm (2011), respectively. The average of monthly rainfall over the past 10-year period was 232 mm, with the highest in December (403 mm) and the lowest in September (144 mm). The months of May to September received relatively low average of monthly rainfalls ranging from 144 mm to 262 mm. The absence of the average of monthly rainfall with less than 100 mm indicated a seasonal climate of the site. During the last decade, unusual dry month or month with less than 100 mm rainfall was very rare, being only recorded in June to October of 1994 and 1997; June, July, and September of 2003; and June and July of 2008. Monthly rainfall varied through time, and months with relatively low rainfall showed high variations (Figure 1). Even though, dry month, which defined seasonality of the climate, generally did not occur, people considered May to September as drier periods, and October to April as wetter periods.

Seven trees of *Swietenia macrophylla* with diameters from 10 to 30 cm were selected and harvested in March to April 2013 in the study area to collect wood disc specimens. Each wood specimen of each tree was collected from a stump at 10 cm the above soil surface. All wood specimens were dried, sanded, and digitally photographed. Wood specimens were coded m1 (diameter at breast height, DBH, =10.04 cm), m2 (12.70 cm), m3 (12.98 cm), m4 (13.47 cm), m5 (13.50 cm), m6 (27.90 cm), and m7 (31.76 cm). A cross section of each disc wood specimen that had the longest distance from its pith to the outer wood was selected for measurements of the radial growth rings. The radial growth rings were measured to the nearest 0.001 cm by using ImageJ software. The measurement data of the growth rings were then used to carry out cross dating visually (Fritts and Swetnam 1989). Cross dating was initiated by plotting all widths of growth rings of all seven wood specimens (Y) against time (X). The position of each growth ring of all seven wood specimens was then adjusted and aligned according to the similarity of width patterns of the rings. The aligned width patterns of each wood specimen were then used to determine the age of growth ring by placing the most recent year (2012) at the outermost ring and subsequently increasing ages towards to the inner most ring. The results of the alignment and adjustment of growth rings and determination of ages were used to calculate the mean of annual growth rings, and to conduct a one-way analysis of variance (ANOVA) to determine whether widths of growth rings differed among the trees.

We calculated autocorrelation and mean sensitivity to know the relationship the growth rings and climate. For more detailed analysis to know what time period showing more sensitive growth ring to climate, we calculated the index of ring width. Autocorrelation was calculated to know whether a radial growth ring was influenced by its previous radial growth ring. Low autocorrelation value indicated low influence of the previous growth, and therefore indicated the influence of climate to the growth ring. Meanwhile, mean sensitivity refers to the proportion of change in width of annual ring from two successive growth rings. It reflected how sensitive growth rings to climate fluctuations. Therefore, we used the combination of low autocorrelation and high mean sensitivity of the ring width of wood specimens to indicate whether ring width data were good for dendroclimatology (Laroque 1995). We followed Cook and Pederson (2011) to calculate autocorrelation and mean sensitivity.

$$\text{Autocorrelation (r)} = [\text{sum } (X_i – X_m)\,(X_{i-1} – X_m)]\ [\,(n – 1)\ S_x^{-2}]^{-1}$$

$$\text{Mean sensitivity (ms)} = [\ \text{sum } 2\,(X_i – X_{i+1})\,(X_i + X_{i+1})^{-1}]\ [\,(n-1)\,]^{-1}$$

Where X_{i-1}, X_i, $X_{i+1,}$ X_m, S_x^2 respectively stands for the width of the growth ring at age i-1, i, i+1, the average of annual width, and variance of width.

The index or standardization was developed to remove the variation of the width of growth ring associated with the increasing age of the trees (Fritts and Dean 1992). The Index of ring width (Y axis) was calculated, plotted against age (X) for each wood specimen to know width index pattern. The pattern was used to determine sensitive and complacent series, which reflected growth behavior for all individual trees to the climate. Sensitive and complacent series were age periods respectively showing strong and steady variation of the index values. The sensitive series indicated that the growth of trees was influenced by the climate, while the complacent series showed that climate had a very weak influence to the growth (Schweingruber 1989). The index was calculated by dividing the actual width of a growth ring with its corresponding width value estimated from the model of the growth ring of a wood specimen. The model of the growth ring was developed based on the cubic polynomial equation of the width of the growth rings and their ages. For the purpose to determine the general pattern of relationship between rainfall and stand growth of Big-Leaf Mahogany, we averaged the index of all wood specimens according to its ages (AI). We used this averaged index to know sensitive series, which was then used to run regression analysis between the value of the averaged index (Y axis) and rainfall (X axis).

RESULTS AND DISCUSSION

Results

The average of annual growth rings of young Big-Leaf Mahogany trees ranged from 0.679 cm yr $^{-1}$ to 1.047 cm yr $^{-1}$. The highest average annual growth rings were 1.048 cm yr $^{-1}$ and 1.003 cm yr $^{-1}$, and respectively occurred in trees with DBH of 12.98 cm (m3) and 12.70 (m2). The lowest values, 0.597 cm yr $^{-1}$ and 0.679 cm yr $^{-1}$, were respectively found in trees with DBH of 31.76 cm (m4) and 27.90 cm (m7) (Figure 2). There was no statistically significant result indicating correlation between diameter and the annual growth ring (Table 1).

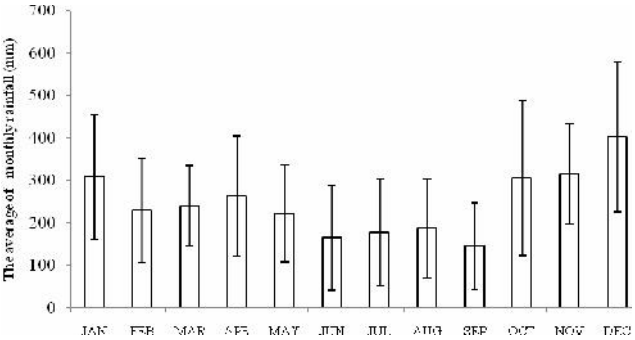

Figure 1. The Average of monthly rainfall recorded at Climatology Station of The University of Bengkulu. Indonesia from 1993-2013

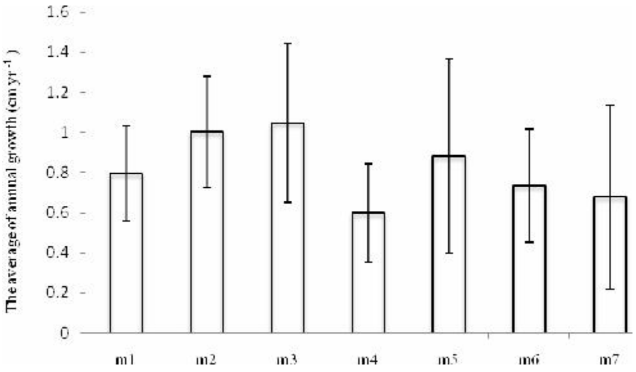

Figure 2. The average of annual growth rings (cm yr $^{-1}$) of Big-Leaf Mahogany trees in Bengkulu, Sumatra, Indonesia. The seven trees were coded as m1 (DBH=10.04 cm), m2 (12.70 cm), m3 (12.98 cm), m (13.47 cm), m5 (13.50 cm), m6 (27.94 cm), and m7 (31.76 cm)

Table 1. The result of ANOVA of regression analysis between the average of growth ring and diameter of Big-Leaf Mahogany trees

	df	SS	MS	F	Significance F
Regression	1	0.036	0.035	1.359	0.296^{ns}
Residual	5	0.131	0.026		
Total	6	0.166			

Table 2. The result of ANOVA to compare the average of annual growth ring width of Big-Leaf Mahogany trees

Source	df	Sum of squares	Mean of squares	F-test
Tree	6	1.292	0.215	1.533^{ns}
Error	54	7.588	0.141	
Total	60	8.880		

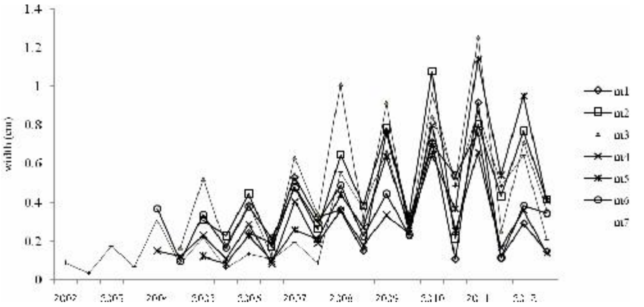

Figure 3. The variation of the widths of growth rings of Big-Leaf Mahogany trees according to ages in Bengkulu, Sumatra, Indonesia. The seven trees were coded as m1, m2, m3, m4, m5, m6, and m7.

Furthermore, the average of the annual growth ring was not significantly different among seven Big-Leaf Mahogany trees (Table 2). Coefficient variation of the width of annual growth rings varied among trees and was considered high. Trees with DBH of 13.50 cm (m5) and 27.90 cm (m6) respectively showed the lowest and highest coefficient variations, while both the smallest (10.04 cm, m1), and the largest DBH (31.76 cm, m7) appeared to have high variations (61.22% and 63.11%). Our result on the variation of growth ring through time showed three interesting patterns (Figure 3): (i) The width of growth rings showed periodicity, where broad width was followed by narrow one; (ii) The width appeared narrow in the young ages and became wider as trees grew older; and (iii) The width steadily increased over time until 2011, after which time the widths somewhat narrowed.

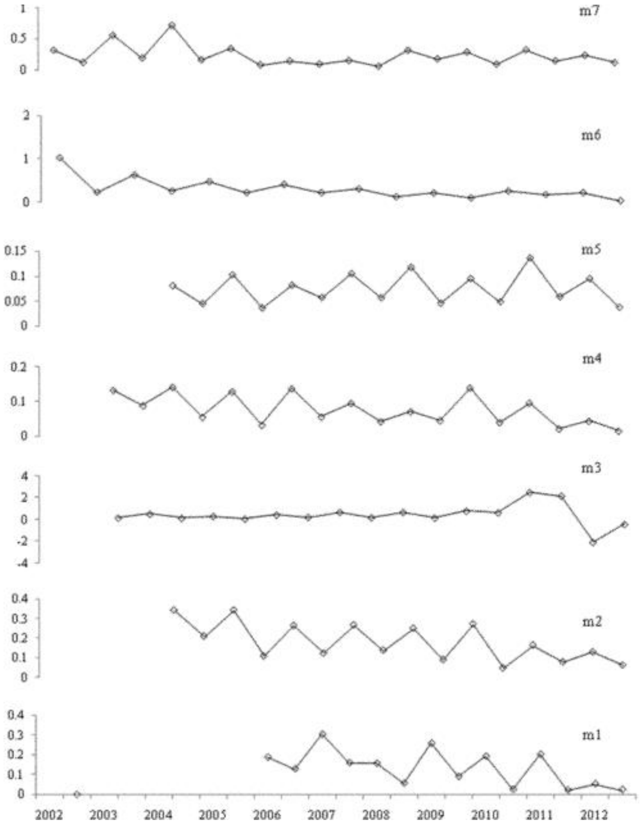

Figure 4. The index of annual ring width of Big-Leaf Mahogany trees (Y-axis) in Bengkulu, Indonesia. The seven trees were coded as m1, m2, m3, m4, m5, m6, and m7.

All wood specimens had high mean sensitivity (0.693-0.988) and low autocorrelation (0.076-0.42), except to trees of m2 and m7, which respectively had high autocorrelations (0.943. and 0.896) (Table 3). These figures reflected that the width of annual growth rings of all trees showed good responses to the variation of climate, except to m2 and m7 trees.

In the individual tree level, the index of growth ring width of all wood specimens showed interesting patterns based on sensitive and complacent series. The index of m1, m4, and m5 showed that they varied through ages. It also indicated that these trees were relatively responsive to climate through the time. Meanwhile, trees of m3, and m6 responded differently. The index of m3 was steady in the first eight years (complacent series), and then was varied in the last three years (sensitive series). In the other hand, the index of m6 had sensitive series in the early stages, and showed complacent series at the later ages (Figure 4).

Table 3. The mean sensitivity and autocorrelation of growth ring width for Big-Leaf Mahogany. The seven trees were coded as m1, m2, m3, m4, m5, m6, and m7. AI refered to the averaged values of the growth ring widths of all wood specimens (m1 to m7)

	m1	m2	m3	m4	m5	m6	m7	AI
Mean sensitivity	0.8963	0.7718	0.9883	0.8042	0.6933	0.7730	0.8275	0.8478
Autocorrelation	-0.4203	-0.9429	0.3938	-0.2137	0.2247	-0.1316	0.8967	0.0761

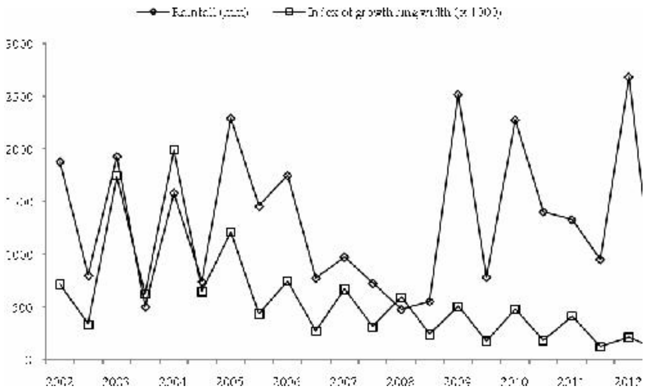

Figure 5. The Index of annual growth ring width for Big-Leaf Mahogany stand and annual rainfall (mm).

Table 4: The results of analysis of correlation between the index of growth ring width of Big-Leaf Mahogany stand and rainfall

	df	SS	MS	F	Significance F
Regression	1	1.301	1.301	6.153	0.033*
Residual	10	2.114	0.211		
Total	11	3.415			

In the stand level, sensitive series were apparent between 2002 and 2007, and followed by complacent series occurring from 2008 to 2012 (Figure 5). We run only regression analysis between index and rainfall during 2002 to 2007. The result of our regression analysis between the index of growth and rainfall demonstrated that during this first six years, the index of growth was positively correlated with rainfall (R= 0.617) (Table 4). On the other hand, we did not run regression analysis data between 2007 and 2012, because the growth ring width appeared independent to rainfall variation (Figure 5).

Discussion

Based on the results of our study, the average of annual growth rings (0.679 to 1.047 cm yr $^{-1}$) of trees was within the range of the observed diameter growth rates of the same species in Belize, Central America. The diameter growth rate in the Belize's study ranged from 0.69 cm yr $^{-1}$ to 1.21 cm yr $^{-1}$, where the fastest growth of individual trees reached 2 cm yr $^{-1}$ (Shono and Snook 2004). The average of annual growth was highly varied among trees, and tendency that larger diameter had smaller width increments was not presence. This was partly caused by the high variation of the width of growth rings within a tree. Such high variation was reflected by the fact that both trees with the smallest and largest DBH had considerably similar high coefficient variations of the width of growth rings. The variation of width as expressed the growth of Big-Leaf Mahogany was also reported by Sebastian et al. (2015). Ruger et al. (2011), who studied impacts of light availability and diameter to diameter growth of 274 woody plants of Barro Colorado Island, Panama, reported that diameter was less responsible to the variation growth rate, than that of soil characteristics. They further predicted that half of the trees performed faster growth rate either in smaller and bigger diameters, respectively. It appeared that the diameter did not produce a strong influence on the variation of width series, but climatic fluctuation and tree maturity.

Our result indicated that the rhythmic pattern of the width of growth rings through time was presence, despite of wet climate. This was contrary with the common beliefs, where in wet tropical climate, the annual growth was continuous, and therefore the distinct tree rings were very rare. The very rare distinct tree rings were caused by the lack of seasonal climate under high rainfall condition (Groenendijk et al. 2014). However biological periodicities were not uncommon in the Southeast Asia tropical forests as reflected by the incidence of flowering and fruiting phenologies (Bawa and Krugman 1991). Furthermore, the result of our research also supported the findings of Fichtler and Clark (2003), who carried out research in La Selva wet tropical forests, and Lopez et al. (2012), who studied tree rings in Bolivian tropical moist forests. Fichtler and Clark (2003) found that six observed species showed distinctive tree rings, and the other two species displayed indistinctive rings. Meanwhile, Lopez et al. (2012) found that seven species showed annual rings. Fichtler and Clark (2003) further explained that even in the wet tropics, plants could experience drought stress, which further caused distinctive tree rings. The drought stress was triggered by the presence of relatively drier and wetter periods and the incidence of unusual low rainfall in drier periods. In La Selva, drier and wetter periods were months with rainfall of 156-271 mm month $^{-1}$ and 353-527 mm month $^{-1}$, respectively. Both similar conditions appeared to occur in the research site. These reasons could explain the distinctive tree ring in our research.

Our result showed increasing width of growth rings with increasing ages, except to the last two years. This pattern was comparable to the result of similar research on Big-Leaf Mahogany at Belize (Shono and Snook 2004). This pattern was common growth development in trees, where they tended to grow higher than to grow larger in diameter at younger ages, but they then gradually switched to grow larger in diameter as they grew older (Halle et al. 1978). However, this result was deviated with the general pattern showing that older and larger diameter trees tended to have smaller width increments than younger and smaller ones (Norton and Ogden 1987; Helama et al. 2004). The deviation of the general pattern could be explained by several reasons. We speculated that all the trees was classified as juvenile phase, which generally performed accelerating growth, therefore the growth rate was higher at older ages. On the other hand, trees of maturity phase demonstrated de-accelerating rate, therefore the growth rate was slower at older ages. In our study, all wood samples also came from young Big-Leaf Mahogany trees (6-12 years), and their canopy developments may attribute to the growth pattern. Their leaf crown structures and volumes were still developing and responsible to the increasing width in the young ages. As the leaf crown approached to its full development, the annual growth would be decreased. Worbes (2002) also reported that young trees have different physiological responses compared to the old trees. Furthermore, the index of growth ring width also indicated that the growth ring of Big-Leaf Mahogany stand tended to be more positively responsive to rainfall in the first six years than that of the later ages; therefore it was expected to have increasing widths in younger ages. These ecological and physiological aspects may cause the annual growth ring pattern of the young Big-Leaf Mahogany. This pattern of the annual growth ring was apparently common growth behavior among Big-Leaf Mahogany stands elsewhere. Data from South Kalimantan, Java, and Nusa Tenggara, Indonesia showed that growth rate of Big-Leaf Mahogany increased until 10 years old, but declined after that age, and finally leveled after 30 years old (Krisnawati et al. 2011). Furthermore, Sebastian et al. (2015) reported that the quadratic growth model of Big-Leaf Mahogany planted in an agroforestry system in Gunungkidul, Yogyakarta, Indonesia, showed that the diameter growth increased with increasing ages, but its rate started to decrease after 20 years old.

A more detail examination of the index of growth ring width revealed interesting growth variations for each tree. The index basically eliminated only age-influenced growth, and therefore reflected effects of climate, local disturbance, environmental conditions, as well as unknown factors, to the annual growth ring (Fritts and Swetnam 1989). The strong association between climate and annual growth ring had been reported by Stahle (1999), Worbes (2002), Pumijumnong and Wanyaphet (2006), Baguinon et al. (2008), Liang and Eckstien (2009), Wils et al. (2010), and Sigal (2011). However, all of these studies came from areas with distinct dry and wet seasons, therefore the climate especially rainfall was expected to cause significant effects to generate distinctive growth rings. For a seasonal region such in Bengkulu, the effects of climate did not necessarily occur throughout ages in the stand level. The positive influence of rainfall to the annual growth ring of Big-Leaf Mahogany appeared in the first six years. In the first six years, the annual growth was increased accordingly with rainfall. Furthermore, a strong positive correlation between rainfall and growth of Big-Leaf Mahogany in natural forests in Belize, Central America was also reported by Shono and Snook (2004). They found that in a wetter year, Big-Leaf Mahogany showed higher annual growth than that of in drier years. In our study, after six years old, the annual growth ring was not influenced by rainfall, and was apparently independent to rainfall. Furthermore, based on the pattern of index at individual level, trees of m1, m4, and m5 showed similar sensitive responses to climate through ages, while the two other trees, m3 and m6, had strong responses either in the early or later ages. On the other hand, the effects of climate to the growth of trees of m2 and m7 were compounded by the effects of diameter as shown by their high autocorrelations. It can be inferred that individual trees did not perform growth responses similarly to climate through ages, even though they grew in the same site and climatic regime. Climate can affect the growth of Big-Leaf Mahogany trees either throughout ages or a certain period of ages. These different responses suggested that the growth pattern cannot be sufficiently explained by climate only. Other factors could play more important roles than the climate to influence the growth of trees. The variation of local environments including microclimate, nutrient distribution, soil moisture (Guindon and Kits 2012), genetic variability, competition among trees for limiting factors (Bascrietto et al. 2004), and canopy closure (Fritts and Swetnam 1989) can cover up the influence of climate on the tree growth. The role of local environments hindered the influence of climate has been reported by Pumijumnong and Wanyaphet (2006). They found that intra-annual variation of tree growth was influenced by local soil moisture, and not by rainfall and temperature. Meanwhile, Sebastian et al. (2015) reported that low soil pH was responsible to generate retarded growth of Big-Leaf Mahogany in agroforestry system in Gunungkidul, Yogyakarta, Indonesia. High variation of annual growth rings as a result to different responses of each tree to climate and local environments may be attributed to insignificantly different mean annual growth rings among trees.

To conclude, the average of annual growth rings varied from 0,679 cm/year to 1,047 cm/year, and was not significantly different across sampled trees. Presence of growth periodicity, high mean sensitivity and low autocorrelation of majority of trees and growth periodicity indicated that Big-Leaf Mahogany was a good species for dendrochronology study in the wet tropics. The width of growth ring increased with ages, but somewhat narrowed in the last two years. In the individual tree level, each tree responded differently to climate. Two of them were responsive to the climate variations through out ages; the others were responsive either in the young or the older ages. The stand of Big-Leaf Mahogany appeared to have strongly sensitive to climate in the early ages or the first six years. Its growth ring had a positive correlation to rainfall in the first six years. The last five years, the annual growth ring of Big-Leaf Mahogany stand was independent, or not affected by rainfall. We speculated that local environments and ecological processes could mask the influence of rainfall to the annual growth ring in the older Big-Leaf Mahogany.

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