UNIVERSITI PUTRA MALAYSIA

VARIATION IN ANNUAL PERIODICITY OF WOOD FORMATION IN SELECTED TROPICAL RAIN FOREST TREES WITH DIFFERENT STEM SIZE

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By

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VARIATION IN ANNUAL PERIODICITY OF WOOD FORMATION IN SELECTED TROPICAL RAIN FOREST TREES WITH DIFFERENT STEM SIZE

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August 2016

Chair : Associate Professor Mohd Zaki bin Hamzah, PhD
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Knowledge on tropical rainforest tree growth patterns and their response to climate is essential for ecological interpretation. However, detailed information on radial growth dynamics of tropical rain forest trees and its variation with tree size, as well as its climate-growth relationship, is still very limited. Relatively, only a few studies have been done on tropical trees growing in less distinct seasonal climate. Thus, the aim of this research was to investigate the variation of tree growth in response to climatic factors and tree size.

Two pioneer tree species (*Macaranga gigantea* and *Endospermum diadenum*) and three late-successional tree species (*Shorea leprosula*, *Shorea parvifolia* and *Shorea acuminata*) were selected for this study. All the sampled trees were grown in lowland dipterocarp rainforest of Ayer Hitam Forest Reserve in Selangor, Malaysia. Three methods, which are monthly dendrometer measurement, cambial activity analysis through monthly wood-sampling and knife-cutting method, were applied in this research from March 2013 to March 2014 to determine the radial growth and vessel formation of the sample trees.

Results showed that trees with different stem sizes of the same and different species showed different growth patterns at site with similar growing conditions. Total monthly rainfall was not the main factor in determining the radial growth of trees growing in humid forest with less distinct seasonal climate. Meanwhile, cambial activity of the examined species showed periods of active growth that alternate with periods of inactive growth. Sample trees showed species-specific responses during the monitoring period. It is believed that trees with different life forms have different growth strategies and thus react differently to climatic event. Relative humidity and vapour pressure deficit are important factors influencing the cambial activity of late successional species, especially in trees with larger stem size. Sampled trees formed periodical variations of vessel features (vessel frequency and vessel lumen area) based on their stem size besides species-specific response to environmental factors. Additionally, the inconsistency of vessel pattern formation in different stem sizes and life stage suggests that vessel formation can be influenced by other growth factors, in addition to climatic factors. Trees formed more than one cycle in both vessel features and thus showed that the periodicity of vessel features is not necessarily annual.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

VARIASI DALAM PERBENTUKAN KAYU TAHUNAN POKOK HUTAN HUJAN TROPIKA TERPILIH DENGAN SAIZ BATANG POKOK YANG BERBEZA

Oleh

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Pengetahuan mengenai corak pertumbuhan pokok-pokok hutan hujan tropika dan kesannya terhadap iklim adalah sangat penting untuk interperitasi ekologi. Namun, kefahaman terperinci mengenai pertumbuhan dinamik diameter pokok hutan hujan tropika dan variasinya dengan saiz batang pokok dan juga hubungan antara pertumbuhan pokok tersebut dengan iklim adalah sangat terhad. Kajian yang dilakukan terhadap pokok-pokok hutan tropika yang tumbuh di kawasan iklim bermusim yang tidak ketara amat kurang dilakukan. Oleh itu, kajian ini dijalankan untuk mengkaji variasi dalam pertumbuhan pokok-pokok tersebut dan kesannya terhadap saiz batang pokok yang berbeza serta hubungannya dengan iklim.

Dua pokok spesies perintis tropika iaitu *Macaranga gigantea* dan *Endospermum diadenum*, serta tiga spesies pokok primer tropika iaitu *Shorea leprosula*, *Shorea parvifolia*, dan *Shorea acuminata* telah dipilih untuk kajian ini. Semua pokok yang dipilih tumbuh di hutan hujan tanah rendah dipterokap, Hutan Simpan Ayer Hitam. Tiga kaedah yang digunakan untuk mengesan pertumbuhan diameter dan pembentukan vesel pokok sampel dari Mac 2013 hingga Mac 2014 ialah pengukuran dendrometer bulanan, analisis aktiviti kambial melalui "wood sampling" bulanan, dan kaedah "knife-cutting" (mencederakan pokok dengan pisau penanda).

Keputusan dari pengukuran dendrometer menunjukkan bahawa pokok yang mempunyai saiz batang berbeza dari spesies yang sama atau spesies berbeza mempunyai pola pertumbuhan berbeza walaupun mereka tumbuh di kawasan yang sama. Jumlah curah hujan tahunan bukan merupakan faktor utama dalam menentukan pertumbuhan diameter pokok-pokok yang tumbuh di hutan hujan tropika dengan iklim bermusim yang tidak nyata. Semua sampel pokok menunjukkan aktiviti kambium yang aktif dan tidak aktif sepanjang tempoh kajian. Semua sampel pokok juga menunjukkan tindak balas spesies khusus terhadap iklim dalam tempoh pemantauan. Hal ini berlaku kerana pokok-pokok yang mempunyai ciri-ciri yang berbeza akan mempunyai strategi pertumbuhan yang berbeza serta bertindak balas secara berbeza terhadap iklim. Kelembapan bandingan dan nilai defisit tekanan wap merupakan faktor penting yang mempengaruhi aktiviti kambium pokok primer tropika terutama pada pokok yang

bersaiz besar. Semua sampel pokok membentuk ciri-ciri vesel (kekerapan vesel dan luas lumen vesel) yang berbeza berdasarkan saiz pokok dan tindak balas khusus setiap spesies pokok terhadap faktor persekitaran. Selain itu, pokok membentuk lebih daripada satu kitaran dalam kedua-dua ciri-ciri vesel dan dengan itu menunjukkan bahawa pembentukan ciri-ciri vesel tidak semestinya dalam bentuk tahunan.

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I certify that a Thesis Examination Committee has met on 18 August 2016 to conduct the final examination of Wang Kang Han on her thesis entitled "Variation in Annual Periodicity of Wood Formation in Selected Tropical Rain Forest Trees with Different Stem Size" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Symbol	Description
DBH	Diameter at Breast Height
C	Compartment
M. gigantea	*Macaranga gigantea*
MGS	*Macaranga gigantea* with smaller stem size
MGB	*Macaranga gigantea* with larger stem size
E. diadenum	*Endospermum diadenum*
EDS	*Endospermum diadenum* with smaller stem size
EDB	*Endospermum diadenum* with larger stem size
S. leprosula	*Shorea leprosula*
SLS	*Shorea leprosula* with smaller stem size
SLB	*Shorea leprosula* with larger stem size
S. acuminata	*Shorea acuminata*
SAS	*Shroea acuminata* with smaller stem size
SAB	*Shorea acuminata* with larger stem size
S. parvifolia	*Shorea parvifolia*
SPAS	*Shorea parvifoila* with smaller stem size
SPAB	*Shorea parifolia* with larger stem size
DDSA	Dodecenylsuccinic anhydride
MNA	Methylnadic anhydride
DMP-30	2.4.6- Tris- (dimethylaminomethyl)phenol 95%
PAS	Periodic Acid-Schiff's reaction

DPX	Dibutyl phthalate xylene
PH	Phloem
CZ	Cambial zone cell
EZ	Enlarging zone cell
V	Vessel
MX	Maturing xylem
VF	Vessel frequency
A	Vessel lumen area
dr	Radial vessel diameter
dt	Tangential vessel diameter

CHAPTER 1

INTRODUCTION

1.1 Background

Seasonal changes in environmental conditions are less pronounced in most tropical region than in the temperate region. This may relate to the clear periodicity of radial growth in temperate trees compared to tropical trees (Nobuchi and Sahri, 2008). The absence of distinct growth rings in tropical trees is believed to be due to the less clear seasonality in the tropical areas (Rozendaal and Zuidema, 2011). Recent research has reported the existence of growth rings in tropical trees, even in evergreen forests (Chowdhury *et al*., 2008; Dünisch *et al*., 2003). Although some tropical trees exhibit growth rings, their seasonal characteristics are often unclear, especially in humid forest with lack of seasonality (Worbes, 2002).

Climate variation is one of the factors affecting radial growth and wood formation in trees. The relationship between tree growth and climate factors is important to any ecological interpretation, dendrochronological analysis and silvicultural systems. Nevertheless, detailed information on this climate-growth relationship and its variation with tree size/age is often missing. Lesser attention has been given to the effects of tree size to radial growth of trees. In the absence of this information, it is often assumed that trees of different-sizes show similar sensitivity to growing conditions. A previous study has shown the relationship between tropical tree growth and climate factors as size-dependent as tropical trees exhibit different growth characteristics during different life stages (Wang *et al*., 2014). Thus, focus should be given to the effects of tree size to climate-growth relationship as it may weaken the climate signal of the chronology, particularly when the climate response is strongly size dependent.

Apart from that, the capability of slow-growing trees to live longer than their fast-growing counterparts has been studied widely and often informally observed across a range of species (Black *et al*., 2008). The long-lived species, which refer to the late-successional species, typically grow more slowly, reach sexual maturity later in life and maintain lower rates of photosynthesis and respiration than that of short-lived species which are frequently referred to early-successional species (Loehle, 1988; Bazzaz, 1979). These trends have been reflected in tree-ring data which indicate that shorter-lived species have faster radial growth rates than long-lived species that grow in the same sites (Black *et al*., 2008). Some studies carried out on temperate trees that included the radial growth rates of the long-lived late-successional eastern hemlock *Tsuga canadensis* revealed that it consistently has slower radial growth than those of the short-lived eastern white pine *Pinus strobe*s (Abrams *et al*., 2000; Abrams and Orwig, 1996). In tropical rainforests, studies on radial growth characteristics between early-successional and late-successional tree species are still limited and hence the information in this aspect remains lacking.

Numerous techniques have been applied to evaluate the radial growth of tropical trees. Tropical trees' growth can be studied by evaluating dendrometric, anatomical, physiological and environmental factors influencing radial growth of trees, and developing empirical mathematical models (Yáñez-Espinosa *et al*., 2006). Among the techniques, most research on tree growth has been carried out by using wood anatomical approaches. Wood anatomical analysis, which is a dynamic process, is able to indicate the dynamics processes of tree growth and development (Wimmer, 2002). Both the macro and micro levels of anatomical structure can provide useful information in predicting the growth pattern of trees under different conditions.

Based on the background described above, the current study therefore attempted to investigate the radial growth dynamics of selected tropical trees with different successional status and stem sizes growing under natural conditions by applying wood anatomical approaches. The first technique involved measuring the periodicity of tree growth through band-type dendrometer (Liming, 1957) over a growing season so as to provide information on the diameter growth pattern of living trees. The second method was intact wood block collections. Collection of wood blocks included inner bark, cambium and outer sapwood in order to observe the periodic of cambial structure and cells derived from it. The third technique was the knife-cutting method (Fujiwara, 1992). Annual variation in vessel features (vessel frequency and vessel lumen area) in trees could be observed through anatomical changes after wounding which mark the time of knife insertion in the tree trunk. Investigation on radial tree growth dynamics is important for the understanding of annual wood formation in tropical regions. The investigated tree species in this study ranged from early-succesional species to late-successional species. The anatomical structure of tropical pioneer and late-successional species was analysed by using different ranges of diameter at breast height (DBH), which also represented different tree ages. Meanwhile, the comparative approach was used to study the growth pattern of the tree species undertaken in this study. This is relevant to understand the natural process of forest dynamics in which the processes are part of the natural order after disturbance (Cabe, 1992).

1.2 Problem Statement

The concept of continuous tree growth in tropical zones and the formation of less distinct growth rings in tropical trees has been a major debate and thus result in limited information on tropical tree growth characteristics. Seasonal changes in environment condition, such as short drought periods, induce rhythmic growth of trees (Wang *et al*., 2013; Worbes, 2002). Worbes (1999) reported that a dry period of three months with rainfall less than 50mm would result in the formation of growth ring in tree growing in tropical forest. Fichtler *et al*. (2013) proved that trees growing in humid climate condition with rainfall more than 100mm for all months are able to form annual ring. These studies showed that small variation in rainfall in humid forest may result in the formation of tree ring.

Studies have shown that radial growth of many tree species is influenced by climatic factors (Pumijumnong and Buajan, 2013; Rozendaal and Zuidema, 2011). Jacoby (1989) and Worbes (2002) stated that distinct environment conditions trigger seasonal

growth in tropical and subtropical tree species leading to formation of annual growth rings. Nevertheless, tropical trees may show species-specific responses to different climatic changes. Thus, these species may reflect different growth strategies (Couralet *et al*., 2010). Despite the nature of the underlying process, our knowledge regarding radial growth characteristics of tropical rain forest trees during a growing season is still very limited and thus further investigation needs to be carried out. Adequate attention was not given to the similarities or differences in growth response of tropical trees under similar climatic conditions. Because of the limited number of studies, it is not clearly understand whether different species have similar growth response under similar climatic conditions. This is important for the matter of generalization and application of the study results from one species to another species. Comparative studies should thus be implemented in order to understand the similarities or differences in growth responses among tropical trees. Therefore, this study was done to investigate the radial growth dynamics and seasonal variations of wood formation in tropical tree species belonging to different successional status and stem sizes. The understanding of tree growth in relation to changing climatic factors is important to improve our knowledge on annual wood formation in tropical regions. The results of this research can be used as a reference for future applied research such as dendrochronology and dendroclimatology conducted in tropical rain forests.

In addition, information on the radial growth of tropical tree species is important as deforestation affects global climate change, which will in turn give feedback on the growth of trees and forests. Silvicultural system, which is based on the concept of sustainable use of forest resources, requires information on the radial growth increment of tropical trees and their responses to climate (Worbes, 1999). The understanding of growth reactions to changing climatic conditions is of great importance to derive suitable management options for possible climate change scenarios and successful reforestation efforts (Krepkowski, 2011).

1.3 Objectives

Based on the background described above, the main objective of this study is to investigate the radial growth characteristics of different-sized tropical pioneer and late-successional species from monthly and annual perspectives during one growing season. The specific objectives of this study are as follow:

- To investigate the diameter growth pattern and stem increment of trees with different stem sizes from each species through monthly dendrometer measurements.
- To study the variation of cambial growth dynamics and determine the relationship between cambial activity of trees with different life forms and their responses to climatic factors (total monthly rainfall, monthly mean temperature, monthly mean relative humidity, and vapour pressure deficit) through monthly wood-sampling from stem of trees.
- To examine the changes of vessel features (vessel size and vessel lumen area) of trees, and determine the differences in vessel formation among trees with different life forms in one year period through knife-cutting method.

This research attempted to attain answers to the following questions: (1) What are the radial growth characteristics of selected tropical trees growing in tropical rain forest with a lack of distinct seasonality, (2) the sensitivity of growth in those tropical trees with differences in stem sizes to climatic factors, and (3) the species-specific response of those trees growing under the same environmental conditions.

1.4 Research Hypotheses

This study tested the hypotheses that (1) Both pioneer species show higher diameter growth rate in smaller stem sized trees than larger stem sized trees, while the three late-sessional species show higher diameter growth rate in larger stem sized trees than smaller stem size trees, (2) rainfall is the main climatic driver of the sampled trees, and trees showed higher growth rate in wet months, (3) trees with different stem sizes and species demonstrated different cambial growth dynamic in response to the same climatic condition, and (4) all sampled trees show intra-annual variation in vessel features, and the variation of vessel formation varies among trees with different species and stem sizes within species. Thus, it was estimated that selected tropical rain forest trees show different growth characteristics at different stages of their lifespan.

1.5 Scope of Study

In this research, all the field experiments were carried out at the Sultan Idris Shah Forestry Educational Centre, which is located in the Ayer Hitam Forest Reserve in Puchong, Selangor. The selected tree species for this study were two tropical pioneer species (*Macaranga gigantea* and *Endospermum diadenum*) and three late-successional species (*Shorea leprosula*, *Shorea parvifolia* and *Shorea acuminata*). The species ranged from early-successional to late-successional species. Two diameter classes were selected for every species. All the sampled species were evergreen species and the exact age of the trees was unknown.

This research was conducted for more than two years. It was started in February 2013 to August 2015. All the field experimentals such as dendrometer measurement, monthly wood block collections and knife-cutting were done in one year's period, which started from March 2013 to March 2014). All the field activities were conducted on the last week of every month throughout the one-year experimental period. The remaining time was utilized for laboratory works, analyses and writing up the results.

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