ESTIMATION OF FOREST STRUCTURE AND ABOVE GROUND BIOMASS OF DIFFERENT FOREST TYPES IN SEPILOK FOREST RESERVE USING AIRBORNE LiDAR DATA

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FACULTY OF SCIENCE AND NATURAL RESOURCES
UNIVERSITI MALAYSIA SABAH
2017

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DECLARATION

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ABSTRACT

Estimating the forest structures and above ground biomass (AGB) in tropical rainforest can be crucial because of the complex and dense forests structure. Light Detection and Ranging (LiDAR) measure the vertical structure of the forests and thus hold great potential for characterizing forest structure and quantifying the AGB on tropical forest. Main goal of this study is to identify the relationships for the metrics derived from airborne LiDAR data with the field observed forest structure and AGB within different forest types (alluvial, sandstone hill and heath) in Sepilok Forest Reserve (SFR). 30 sample plots were established in different forest types with the field-measurement of DBH, height as well as tree species. Using the field-measured data, the basal area (BA), Lorey's height (LH) and AGB within each plot were calculated. From the LiDAR data, height metrics (HT^{M}) and laser penetration rates (LP) of different height from the ground were derived and stepwise multiple regressions were performed to select variables to establish the estimation models. Best model with the single variable of LP at 20 m height was used to estimate AGB (R^2 adj=0.58, RMSE=30.15 %). Single variable also was used for best height model of LP at 16 m height (R^2 adj=0.55, RMSE=5.67 %) and LP at 18 m height for BA model (R^2 adj=0.76, RMSE=22.15%). Multiple variables of LP at 24 m height and LP at 1 m height worked best for DBH estimation model (R^2 adj=0.56, RMSE=8.31%), while HT^{70th} and LP at 1 m height were selected for the LH estimation model (R^2 adj=0.88, RMSE=8.64%). The results confirmed the capability of LiDAR data for estimating AGB and forest structure of SFR.

ABSTRAK

ANGGARAN STRUKTUR HUTAN DAN BIOJISIM KAWASAN HUTAN YANG BERBEZA DI HUTAN SIMPAN SEPILOK MENGUNAKAN DATA LiDAR

Menganggar struktur hutan dan biojisim (AGB) di kawasan hutan hujan tropika adalah penting kerana struktur hutan yang kompleks dan tebal. Light Detection and Ranging (LiDAR) mengukur struktur menegak kawasan hutan dan mempunyai potensi yang besar bagi mencirikan struktur hutan dan mengukur AGB di hutan tropika. Matlamat utama kajian ini adalah untuk mengenal pasti hubungan metrik yang diperoleh dari data LiDAR dengan data lapangan struktur hutan dan AGB dalam kawasan hutan yang berbeza (aluvial, bukit batu pasir dan kerangas) di Hutan Simpan Sepilok (SFR). 30 plot sampel telah didirikan di dalam kawasan hutan yang berbeza dengan pengukuran DBH, ketinggian serta spesis pokok diambil. Berdasarkan data yang diukur dari lapangan, kawasan basal (BA), ketinggian Lorey (LH) dan AGB dalam setiap plot dikira. Daripada data LiDAR, metrik ketinggian (HT^{M}) *dan kadar penembusan laser (LP) pada ketinggian yang berbeza dari aras permukaan tanah diperoleh dan analisis regresi dilakukan untuk memilih pembolehubah model anggaran. Model terbaik dengan pembolehubah tunggal LP pada ketinggian 20 m telah digunakan untuk menganggar AGB* (R^{2} *adj=0.58, RMSE=30.15 %). Pembolehubah tunggal juga digunakan bagi model terbaik untuk ketinggian LP pada ketinggian 16 m* (R^{2} *adj=0.55, RMSE=5.67 %) dan LP pada ketinggian 18 m untuk model BA* (R^{2} *adj=0.76, RMSE=22.15%). Pembolehubah berganda LP pada ketinggian 24 m dan 1 m paling sesuai untuk model anggaran DBH* (R^{2} *adj=0.56, RMSE=8.31%), sementara pembolehubah* HT^{70th} *dan LP pada ketinggian 1 m dipilih untuk model anggaran LH* (R^{2} *adj=0.88, RMSE=8.64%). Hasil kajian ini membuktikan keupayaan data LiDAR untuk menganggar AGB dan struktur hutan SFR.*

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LIST OF CONTENTS

Page

TITLE i

DECLARATION ii

CERTIFICATION iii

ACKNOWLEDGEMENTS iv

ABSTRACT v

ABSTRAK vi

LIST OF CONTENTS vii

LIST OF TABLES x

LIST OF FIGURES xi

LIST OF SYMBOLS xii

LIST OF ABBREVIATIONS xiii

CHAPTER 1: INTRODUCTION

1.1 Introduction 1
1.2 Statement of Problems 2
1.3 Objectives 3
1.4 Justification 4

CHAPTER 2: LITERATURE REVIEW

2.1 Tropical Forests and Its Structural Complexity 5
2.2 Forest Biomass 6
2.3 REDD+ Approach in Reducing Carbon Emission 6
2.4 AGB Estimation in Tropical Forest 7
2.5 Applicability of Remote Sensing in Tropical Forest 8
2.6 Airborne LiDAR for Forest Structure and AGB Estimation 10

CHAPTER 3: METHODOLOGY

3.1 Study Site 15
3.1.1 Temperature 16
3.1.2 Rainfall 16
3.1.3 Geography, Topography and Soil 16
3.1.4 Vegetation 17
3.2 Experimental Design 19
3.2.1 Field Data Collection 19
3.2.2 Tree Species Identification 20
3.2.3 Field and GIS Data Processing 20
3.3 LiDAR Data Acquisitions 21
3.3.1 LiDAR Data Processing and Analysis 23
3.4 LiDAR Data Analysis 24
3.4.1 Construction of Canopy Height Model (CHM) 24
3.5 Data Processing and Analysis 27
3.5.1 Field Data Analysis 27
3.5.2 AGB Calculation 27
3.5.3 LiDAR Height and Laser Penetration Metrics 28
3.5.4 Forest Structure Estimation Models 29
3.5.5 Model Evaluation 30

CHAPTER 4: RESULT

4.1 Field Data Analysis 33
4.1.1 Characteristics of The Forests Structure 33
4.1.2 Tree Species Diversity 35
4.1.3 Field-Based AGB 36
4.2 Correlation between Forest Structure Variables, AGB and LiDAR Metrics 36
4.3 Prediction Models of Forest Structure Variables 38
4.4 Performance of the Prediction Models 44
4.5 Mapping of Forest Structure and AGB 48

CHAPTER 5: DISCUSSION

5.1 Structures and AGB of the Forests in SFR 55
5.2 Estimation for Forest Structure Using LiDAR 57
5.3 AGB Estimation Using LiDAR 59
5.4 Limitation 60
5.5 Future Research 61

CHAPTER 6: CONCLUSION

6.1 CONCLUSION 63

REFERENCES 65

LIST OF TABLES

Page

Table 3.1: Area flight profile and LiDAR scanning settings 22

Table 3.2: Basal area and Lorey’s Height formula 27

Table 3.3: Above ground biomass allometric equations 28

Table 3.4: Model evaluation methods 30

Table 4.1: Descriptive summary of the forest structure variables 33

Table 4.2: Forest structure regressed against LiDAR derived metrics 37

Table 4.3: Regression statistic for forest structure 39

Table 4.4: Regression statistic for AGB 41

Table 4.5: Summary of forest structure validation 43

Table 4.6: Summary of AGB estimation 43

LIST OF FIGURES

Page

Figure 3.1: Sepilok Forest Reserve, Sandakan Location 15

Figure 3.2: Soil association map of SFR 17

Figure 3.3: Forest formation map of SFR 18

Figure 3.4: Size of research plots. 19

Figure 3.5: Three different forest types in SFR 21

Figure 3.6: LiDAR data processing 24

Figure 3.7: DSM represents elevation of the tallest surface and DTM represents the elevation of ground 26

Figure 3.8: Canopy Height Model (CHM) production 26

Figure 4.1: Tree density of three different forest types 35

Figure 4.2: Tree family composition 35

Figure 4.3: Graph of observed AGB Using Chave's equation 36

Figure 4.4: Comparison of observed and estimated DBH 44

Figure 4.5: Comparison of observed and estimated HT 45

Figure 4.6: Comparison of observed and estimated BA 45

Figure 4.7: Comparison of observed and estimated LH 46

Figure 4.8: Comparison of observed and estimated AGB 46

Figure 4.9: DBH Prediction Map 48

Figure 4.10: HT Prediction Map 49

Figure 4.11: BA Prediction Map 50

Figure 4.12: LH Prediction Map 51

Figure 4.13: AGB Prediction Map 52

LIST OF SYMBOLS

CO^2	Carbon dioxide
N	Sample size (full sample)
r	R value
R^2	R^2 value
SD	Standard deviation
CE	Chave's equation
3D	3-dimensional
%	Per cent
t/ha	Tonnes per hectares
m	Meter
cm	Centimeter
m^2	Square meter
m^3	Cubic meter

LIST OF ABBREVIATIONS

FRA	Forest Resources Assessments
REDD	Reducing emissions from Deforestation and Forest Degradation
UNFCCC	United Nations Framework Convention on Climate Change
LiDAR	Light Detection and Ranging
GHG	Greenhouse gases
NFI	National Forest Inventory
DBH	Diameter at breast height
AGB	Above Ground Biomass
FRC	Forest Research Center
SFR	Sepilok Forest Reserve
Sg.	Sungai
MRV	Measurement, Reporting and Verification
RMSE	Root Mean Square Error

CHAPTER 1

INTRODUCTION

1.1 Introduction

The Global Forest Resources Assessments (FRA) 2015 reported between years 2010 to 2015 an annual net loss of 3.3 million hectares of forest areas. World's forests have been declining continuously as human population has been on the increase. This triggers the need for food and also land for agriculture. Logging of the forest has been intensified to supply raw materials to the increasing populations. Increasing deforestation and forest degradation have resulted in increasing emissions of carbon dioxide (CO_2) to the atmosphere (Hall and Uhlig, 1991; Houghton *et al.*, 2000; Brown, 2002; Page *et al.*, 2002) that adversely affects climate change. According to Gibbs (2007), the terrestrial forest ecosystems are playing a crucial role in the sequestration and storage of carbon. In addition, he stated that reducing emissions from Deforestation and Forest Degradation (REDD+) is a mechanism to mitigate climate change under the United Nations Framework Convention on Climate Change (UNFCCC); where it requires the developing countries to voluntarily reduce the greenhouse gas emissions below a specific baseline to get financial aid and in return.

Tropical forest has the most complex ecosystems that contribute greatly to global carbon storage (Whitmore, 1984). Reduction of the biomass is mainly caused by the conversion of land uses (Houghton, 2005; Clark *et al.*, 2011) and forest degradation (Nepstad *et al.*, 1999; Clark *et al.*, 2011). Due to these particular changes, a critical monitoring for the tropical forest biomass is needed in improving the understanding of the global ecosystems. Above ground biomass (AGB) is a total amount of living materials which stated as the oven-dry per tones and meanwhile, half of the biomass dries weight is known as carbon pools (Iqbal, 2010). Best approach of estimating the woody forest biomass is by measuring the biophysical parameters of a tree such as height, diameter at breast height (DBH), tree volume and wood density followed by calculating the AGB using allometric equations. Due to the complex forest structure of the tropical rainforest, AGB estimation can be complicated. However, field inventory method consumes lots of time, energy and costs in order to cover wide forest areas in such condition.

Remote sensing applications is the method that alternatively applied to replace the ground inventories (Pouliot *et al.*, 2002; Palace *et al.*, 2008), contributes more information for the larger and inaccessible areas. This technology plays important roles in the estimation of forest's carbon stock, forest monitoring and also in the estimation of forest biomass and management (Reader, 1994). Among remote sensing techniques, Light Detection and Ranging (LiDAR) has been increasingly used for estimating AGB and structure estimation in tropical forests. It has a good potential and capability to be applied in the tropical forest studies as it can provide 3-dimensional (3D) perspective of forest structure and relatively accurate measurement of the tree parameters, especially height (Montaghi *et al.*, 2013; Patenaude *et al.*, 2004).

1.2 Statement of Problems

Optical remote sensing has been useful to estimate forest characteristics. However, according to Gibbs (2007), for estimation through different approaches and methods can result with different level of uncertainties from high to medium and low. Different optical remote sensing data with different spatial resolution have been used in estimation of AGB (Lu, 2006; Luther *et al.*, 2006; Lu *et al.*, 2012), revealing that optical remote sensing data are unable to extract the forest parameters and forest structures directly (Lu *et al.*, 2014). Sometimes cloud and atmospheric conditions especially in the tropical forests areas limits the acquisition of good data from optical sensors. Also, the data saturation problems can be observed where the complex forest structures having high biomass density (He *et al.*, 2013; Lu, 2006).

Airborne LiDAR technology can provide the 3D information and height of the canopy in the forest area which other optical sensors are not capable of. Although there were several studies on estimating AGB throughout the tropical forest applying the DBH data information alone (Brown *et al.*, 1989), the height of trees is an important factor that contributes the calculation of AGB (Ogawa *et al.*, 1965; Brown *et al.*, 1989; Chave *et al.*, 2005). Point clouds derived from the LiDAR data are capable of provide good indication of the forest structural and height of the trees. Thus, the airborne LiDAR technology could be useful to estimate structures of tropical forest. So far, not much research has been conducted to study the forest structure and AGB estimation in different forest types of tropics. Using airborne LiDAR data, this research was conducted to examine if LiDAR technology can be applied for the forest structure and AGB estimation of different forest types in the tropics.

1.3 Objectives

This research's main goal is to identify the relationships for the metrics derived from airborne LiDAR data with the forest inventory data collected in the field within different forest types in Sepilok Forest Reserve (SFR). The approach is tested for its applicability as an input for AGB as well as forest structure estimation purposes. This study was specifically conducted to establish the estimation models for forest structures and AGB by using the airborne LiDAR data. Collection of in situ forest parameters data from alluvial, sandstone hill and heath forest was used for its feasibility for estimation.

Using the estimation models established, this research also aims to map the forest structure and AGB of different forest types in SFR. Forest structures and AGB estimation models were applied to produce prediction map for the whole area of SFR.

1.4 Justification

Focusing on identifying the form of relationship between forest structure and AGB, it justifies the importance of exploring the capabilities of airborne LiDAR technologies in detecting and measuring forest parameters in SFR. Similar to REDD+ implementation, the accurate estimation and monitoring of the carbon stocks are required at the better scale. It can emphasized the necessity of measuring, reporting and verification (MRV) of the forest carbon stocks, so that, a scientific approach with the application of remote sensing data and field data can be applied. It is beneficial for Forestry Department, researchers and other forestry related organizations to understand more about forest structure of different forest types and abilities of airborne LiDAR data in providing useful information. Thus, the outcome of this research would help management parties for monitoring and assessment of future forest management. Contribution to environmental planning, forest management and biodiversity conservation can be implemented more proper and organize as more details acquire to be applied for operational uses. Therefore, monitoring plan can be established effectively and efficiently.

CHAPTER 2

LITERATURE REVIEW

2.1 Tropical Forests and Its Structural Complexity

Tropical forest cover approximately 7% of the global terrestrial surface, across the continents of Asia, Africa and Latin America; which believed to contain over half of the world's species (Wilson, 1992). Rainforest areas experience high average annual temperature and a significant volume of rainfall which can be found in Asia, Australia, Africa, South America, Central America, Mexico, along within Pacific, Caribbean and the Indian Ocean islands (Osborne, 2000). Great variablity in tropical forest around the globe, with wide range of structure and species compositions. Biodiversity levels present here was recorded higher compare to other with 40% to 75% of all biotic species are indigenous to the rainforests (Colwell and Coddington, 1994; Sodhi *et al.,* 2004; Kier *et al.,* 2009). Tropical forests are also known to be structurally complex. Huston (1994) stated that the physical environment for each forest types of forests is different, resulting in different forest structures. Complexity of the forest was relying on the variable species composition and diversity is over space (Pittman, 2000). Structure also varies significantly between tropical forest ecosystems (Pendry and Proctor, 1996; Pendry and Proctor, 1997; Kappelle, 2004). The variability in forest structure can be seen through the canopy, sub-canopy and understorey. This structure stand height has been attributed to many factors, including high humidity, nutrient limitation, low temperature, soil acidity and cloud cover (Odum, 1970; Vitousek, 1984; Vitousek and Sanford, 1986, Kitayama and Aiba, 2002; Hafkenscheid, 2000; Letts, 2003; Grubb, 1977; Letts, 2003).

Among the tropical forests, lowland tropical rainforests has potential to integrate and store carbon in large proportions due to the recruitment and growth rate of trees (Whitmore, 1984; Kuusipalo *et al.,* 1996; Pinard and Cropper, 2000;

Swaine and Agyeman, 2008; Tanaka *et al.,* 2009). However, the tropical rainforest areas are facing most threatened large scale of defragmentation and deforestation as results of anthropogenic activities.

2.2 Forest Biomass

According to Global Terrestrial Observing System (GTOS) (2009), on the status development of the standards for terrestrial climate variables, the vegetation biomass is a crucial ecological variable as to understand the evolution and potential climate system changes in the future. The quantity of biomass the vegetation covers is said to influence the local, region and even global climate directly, in particular on the air temperature and humidity (Bombelli *et al.,* 2009; Rajput *et al.,* 2017). Generally, biomass is important as essential climate variable role; i) for energy production ii) reducing global greenhouse gasses (GHG) emissions. Increasing usage of biomass for production significantly increase the percentage of global GHG emitted from biomass consumption.

Potential of the tropical rainforest area to store carbon as biomass is higher as it is useful for maintaining ecological systems and environmental purposes (Gibbs *et al.,* 2007). Different forest types and conditions hold different biomass content due to several affecting parameters such height, DBH, species composition and wood density (Ketterings *et al.,* 2001).

2.3 REDD+ Approach in Reducing Carbon Emission

Based on the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (2011), it was noted that the emissions of CO_2 from the deforestation and forest degradation in developing countries have a large impact on the global carbon cycle. Denman *et al.* (2007) stated that 80% of CO_2 emitted by fossil fuel combustion and cement product, while the remaining 20% was a result of land-use changes such deforestation. Additionally, it was also reported that about 65% of total mitigation potential in forestry sector is located in the tropics and about 50% from the total could be achieved by reducing emission from deforestation activities (Nabuurs *et al.,* 2007).

REDD+ is an international framework for achieving the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (Hirata *et al.,* 2012). It aims to encourage the reduction of greenhouse gasses emissions from the deforestation and forest degradation, conserving and enhance the forest carbon stock along with sustainable management of forest area. This mechanism requires the measurement of carbon stock changes in the forest which takes into account the insecurity of biomass estimation (Hirata *et al.,* 2012). Originally, REDD+ was just an item on concerning future climate change mitigation agenda under UNFCCC. However, after being modified as UNFCCC discussions continues, it includes all the bilateral and multilateral activities to enhance the forest carbon stocks. It will become a climate change mitigation solution in helping reduce up to 20% of carbon emissions globally. The UNFCCC also emphasized the necessity of measuring, reporting and verification (MRV) of forest carbon stock, and in Conference of the Parties (COP) it adopted a scientific approach with the application of remote sensing data and field data (UN-REDD, 2008; Hirata *et al.,* 2012; Laurin *et al.,* 2014).

The MRV on REDD+ sites is also significant to control the impact of interventions and provide reliable data in verifying REDD+ as a whole (Harold and Skutsch, 2011; Palmer, 2011; REDD-net Programme, 2010). The accurate estimation of forest carbon stock in a sustainably managed forest ecosystem in the countries committed to the REDD+ was one of the main concerns of this programme before the financial incentives being issued (Hirata *et al.,* 2012).

2.4 AGB Estimation in Tropical Forest

AGB refers to the total amount of biomass above the ground, which approximately 47% to 50% of forest total biomass was assumed to be the carbon stock (Malhi and Grace, 2000). Studies on AGB estimation conducted to quantitatively identify the biomass content took place in the tropical rainforest area as it’s contributes to the global carbon cycle (Houghton, 2005; Houghton et al. 2009). Approaches being applied involving different units of biomass estimation; fresh weight (Araujo *et al.,*

1999) and dry weight (Ketterings *et al.,* 2001). Most of the researches were concentrated on AGB (Palace *et al.,* 2008; Morel *et al.,* 2012; Langner *et al.,* 2012) through direct harvesting or non-harvesting method (Brown *et al.,* 1989; Wulder *et al.,* 2008; Roy and Ravan, 1996). Forest inventory methods of non-destructive sampling were based on the statistical relation of field measurements to destructive harvest measurements, and conversion to biomass estimates using allometric equations (Brown, 1997; Chave *et al.,* 2005; Basuki *et al.,* 2009). By classified or grouping all species together and establishing general equations were highly effective for the tropics (Brown, 1997). However, the complexity of structural and biotic in tropical forest causes difficulties for the inventory; i) where the generic relationships were not appropriate for all regions ii) inventories could be expensive and time consuming (Chave *et al.,* 2005; Gibbs *et al.,* 2007).

2.5 Applicability of Remote Sensing in Tropical Forest

Remote sensing technology have been widely applied and implemented into forestry as techniques for providing important information on biomass estimation, forest management and planning and also forest conservation (Chubey *et al.,* 2006; Gibbs *et al.,* 2007; Wulder *et al.,* 2008; Langner, 2009). Jensen (2009) referred that the remote sensing application as the acquisition of data and information about the object or phenomenon without making physical contact. This application was contrast to the on-site observation or fieldwork inventory and makes it possible for data collection in the inaccessible or dangerous areas. It also allows the monitoring processes of deforestation activities in specific areas. In this case, it was capable in replacing costly, slow and laborious data collection on the ground. Remote sensing can be classified into two different classes; i) active remote sensing (e.g. Shuttle Radar Topography Mission (SRTM) etc.) and ii) passive remote sensing (e.g. Landsat-8).

Remotely sensed data have been employed for ecological characterization variables as it may be used to generate a wide range of estimates that are valuable including land cover, vegetation cover, habitat, forest structure and forest function (Kerr and Ostrovsky, 2003; Wulder *et al.,* 2004). From this data, the variables can be used to track changes over times. Fundamentaly, the remote sensed data was used to estimate or map biophysical or forest inventory data as there is a predictable relationship between the spectral responce measured by the sensor and magnitude of the paramaters of interest. The data capturing and processing make it possible to generate and analyze for example digital images at different spatial resolution, which opens more opportunity to estimate wide range of ecologically important attributes such as characterization of vegetation for estimation of stand structural and leaf area index (LAI) (Wulder *et al.,* 2004). It is also stated that the estimation of forest stand structure, including species composition, crown closure, stand height, stem density, age and volume, has been the focus of forest inventories used to ensure that forests are managed on sustainable basis. Forest structure has been the subject of a large number of experimental and empirical studies using the applications of remote sensing data (Wulder *et al.,* 2004). Studies of the applicability of remote sensing to predict the stem density and stand height and stand volume and basal area managed to extract the information on the forest structure at high spatial resolution (Franklin and McDermid, 1993; Wulder *et al.,* 2002). The mapping efforts based on the inventory data and satellite image at coarse spatial resolution not suited and sufficient if its includes too broad interest parameters.

Nilsson (1995) emphasized that remote sensing technology plays an important role in forest's carbon stock estimation, which also play vital role in forest monitoring, biomass estimation and forest management. A study by Hall *et al.* (2006) has mapped AGB in boreal and temperate environments using Landsat ETM+ to derive estimates of AGB and volume from the species composition and forest stand structure information of the conifers species by modelling tree height and crown closure attributes. Mapping of AGB resulted in lower, less variable and more statistically similar to the field values and reported within the range of values reported in previous research (Fazakas *et al.,* 1999; Tomppo *et al.,* 2002; Zheng *et al.,* 2004; Luther *et al.,* 2006). These studies was reported the varying degrees of success mapping AGB by the used of remote sensing data in boreal or temperate forests. In tropical forest environments, Ling *et al.,* (2013) had conducted study using remote sensing on estimating AGB based on individual tree crown delineation