UNIVERSITI PUTRA MALAYSIA

ESTIMATION OF ABOVEGROUND BIOMASS AND CARBON STOCKS IN MATANG MANGROVE FOREST RESERVE USING ALLOMETRY MODEL AND REMOTE SENSING TECHNIQUE

MUHAMMAD EKHZARIZAL BIN MOHAMED EUSOP

FH 2017 11

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

July 2017

All of this is because of you

For my beloved father, ***Mohamed Eusop bin Indran.***

For my lovely mother, ***Norsita binti Buang.***

My eldest brother, ***Muhammad Ekhsan.***

My elder brother, ***Muhammad Ekhwan.***

My younger brother, ***Muhammad Eizlan Haikal***

and

My youngest brother, ***Muhammad Ezzan***

And for all person who was involved to help me to finish this thesis.

Thanks for the support and understanding.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science

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July 2017

Chairman : Mohd Hasmadi bin Ismail, PhD
Faculty : Forestry

Among other forest types, mangrove forest is one of the most important ecosystems. Being able to act as a "sponge" for carbon pools is one of the biological services provided by mangrove forest. Tree biomass estimates and analyses are essential for carbon accounting and other feasibility studies including bioenergy. Mangrove plays an important role in ecosystems which could mitigate the climate change through biomass and carbon storage. Due to concerns on global climate change and carbon sequestration a reasonable method for estimating tree biomass and carbon stocks are highly demanded. Thus, this study was design to estimate the aboveground biomass (AGB) of mangrove trees using allometry model and remote sensing technique. A total of 150 plots from 17 compartments were sampled in 2014. Based on remote sensing technique, SPOT-5 data were used to estimate and mapping aboveground biomass and carbon stocks. Four types of vegetation indices (VI's) were selected and tested in this study. The estimation of AGB was further refined using integration analysis from direct method data. To achieve the objective of this study, optical image and sampling data had been processed and analysed, and validated by using regression model. By using non-destructive method and allometry model, the results shown that average AGB per plot was about 168.93 ton ha^{-1}. The maximum value was 462.40 ton ha^{-1} and the minimum was 24.35 ton ha^{-1} respectively. While average value of carbon storage was 84.47 tonC ha^{-1}. Then, exponential regression model had performed to estimate the AGB along with optical image. The findings demonstrate a good relationship between measured AGB and selected vegetation indices (NDVI and GEMI-NDVI). The others two like SAVI and GNDVI had proved weak relationship with measured AGB. However, the results indicate that there were slightly increase for about 3% with the using multi-exponential regression analysis. Study had further refined by using multi-exponential of integration method from incorporating both predicted NDVI and GEMI-NDVI with coefficient of determination (R^2 = 0.74) which had proved that the increment of 1% compared with multi-exponential of direct method and the overall result for RMS error was 85.24 ton ha^{-1}. This shows that the average estimation of AGB was 130.36 ton ha^{-1}. Therefore, total amount of AGB for the whole study area in Kuala Sepetang (South) (9,884 ha) approximately of 1.3 million tonnes. The amount of AGB was 1.80% slightly overestimated compared with previous study by using

destructive sampling. Thus, the studies had suggested that the non-destructive sampling by using common allometric equation is still effective and reasonable to be used for the estimation on AGB in mangroves forest. The correlation and regression analysis were done separately between AGB and vegetation indices by using direct method and integration method. Results had shown that the multi-exponential integration method is highly in accuracy and strongly correlated with the field data among the others correlation. In conclusion, the study indicates that the common allometric equation for calculating AGB was applicable for all mangrove species instead of species-specific equation. With the using of remote sensing technique and multi-exponential integration analysis, the estimated biomass and carbon stocks were slightly increased for about 1%. The regression model developed may be useful for estimating the AGB of areas that are not reachable and in low cost. The study using satellite imagery data was an attempt to improve the estimates by integration method as a final outcome for better conversion of biomass to carbon stock content.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

PENGANGGARAN BIOJISIM DI ATASTANAH DAN STOK KARBON DI HUTAN SIMPAN PAYA BAKAU MATANG MENGGUNAKAN MODEL ALOMETRI DAN TEKNIK PENDERIAAN JARAK JAUH

Oleh

MUHAMMAD EKHZARIZAL BIN MOHAMED EUSOP

Julai 2017

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Antara jenis hutan, hutan paya bakau merupakan salah satu ekosistem juga penting. Kemampuannya sebagai "span" bagi penyerapan karbon merupakan salah satu perkhidmatan biologi yang disediakan oleh hutan bakau. Menganggar dan menganalisa biojisim juga merupakan sesuatu yang penting untuk pengiraan karbon dan kajian kemungkinan mengenai biotenaga. Paya Bakau memainkan peranan yang penting di dalam ekosistem kerana ia juga boleh mengekang perubahan iklim melalui biojisim dan penyimpanan karbon. Disebabkan isu perubahan iklim global dan kitaran karbon maka satu usaha perlu dilakukan untuk menganggarkan biojisim pokok dan kadar simpanan karbon. Kajian ini dilaksanakan adalah untuk menganggar biojisim atas tanah (AGB) pokok bakau menggunakan model allometrik dan penderiaan jauh. Sebanyak 150 plot kajian daripada 17 kompatmen telah dibuat pensampelan pada tahun 2014. Berdasarkan teknik penderiaan jauh, data SPOT-5 telah digunakan untuk menganggar dan pemetaan AGB dan stok karbon. Empat jenis Index Tumbuhan (VI's) telah dipilih di dalam kajian ini. Anggaran AGB selanjutnya ditambah baik dengan menggunakan analisis secara integrasi daripada data kaedah langsung. Bagi mencapai objektif kajian, data optikal dan data lapangan telah diproses dan dianalisa serta ditentusahkan dengan menggunakan model regresi. Melalui kaedah "non-destructive method: dan model allometrik keputusan menunjukkan purata AGB bagi setiap plot adalah kira-kira 168.93 tan ha^{-1}. Nilai maksimum ialah 462.40 tan ha^{-1} manakala minimum pula 24.35 tan ha^{-1}. Nilai purata bagi penyimpanan karbon ialah 84.47 tanC ha^{-1}. Kemudian, model regresi ekponen telah dilaksanakan untuk pengiraan AGB bersama dengan imej optikal. Keputusan menunjukkan ada kaitan hubungan yang baik antara AGB dengan Index tumbuhan yang telah dipilih. Index yang lain seperti SAVI dan GNDVI telah terbukti mempunyai hubungan yang lemah dengan AGB. Namun begitu keputusan menunjukkan bahawa terdapat sedikit peningkatan sebanyak 3% dengan menggunakan penggabungan jenis analisis regresi ekponen. Kajian telah menggabungkan kedua-dua NDVI dan GEMI-NDVI dengan pekali penentuan (R^2 = 0.74) dan telah memberikan bahawa peningkatan sebanyak 1% jika dibandingkan dengan kaedah penggabungan langsung ekponen. Jumlah keseluruhan jumlah ralat RMS ialah 85.24 tan ha^{-1}. Ini menunjukkan bahawa purata anggaran AGB ialah 130.36 tan ha^{-1}. Maka, jumlah AGB bagi keseluruhan kawasan kajian di Kuala Sepetang (Selatan) (9,884 ha) adalah kira-

kira 2.8 juta tan. Dapatan ini menunjukkan sekitar 1.80% melebihi berbanding dengan kajian pensampelan "non-destructive method". Korelasi dan analisis regresi telah dibuat secara berasingan di antara AGB dan indeks tumbuhan dengan menggunakan kaedah secara langsung dan kaedah integrasi. Keputusan telah membuktikan bahawa kaedah integrasi gabungan linear amat berkesan dan kuat di dalam hubungkait berbanding korelasi yang lain. Kesimpulannya, kajian menunjukkan bahawa persamaan alometrik biasa bagi pengiraan AGB boleh digunakan untuk kesemua spesis bakau berbanding persamaan spesis secara spesifik. Dengan menggunakan teknik penderiaan jauh dan analisis penggabungan linear, anggaran biojisim dan stok karbon sedikit meningkat iaitu sebanyak 1%. Pengembangan model regresi ini wajar digunakan untuk pengiraan AGB bagi kawasan yang tidak boleh dimasuki dan dengan kos yang rendah. Kajian ini menggunakan data imej satelit merupakan satu pendekatan untuk meningkatkan nilai anggaran dengan menggunakan kaedah integrasi sebagai satu penambahkbaikan kepada nilai anggran biojisim seterusnya bagi penukaran yang lebih baik dari biojisim kepada stok karbon dengan lebih tepat.

ACKNOWLEDGEMENTS

In the name of Allah S.W.T., most benevolent, ever merciful
All praise to be to Allah S.W.T.

First and foremost, Alhamdulillah all praise to the almighty Allah S.W.T. for his blessings and opportunity to complete this project. Foremost, I would like to express my sincere gratitude to my supervisor Assoc. Prof. Dr. Mohd Hasmadi bin Ismail for his invaluable guidance and supervision, construction criticism and enthusiastic encouragement that made this work possible. His comments, time and involvement have played a significant role in improving the work seen in this thesis. My sincere thanks also go to Dr. Muhd Roslan bin Mohd Kassim for helping me his valuable suggestion and guidance for this project.

Special thanks to the staff from "Pejabat Hutan Daerah Larut dan Matang", "Pejabat Renjer Hutan, Kuala Sepetang for their supply of data. Greatest appreciation goes to En. Mohd Faris bin Sobri, District Forest Officer and all the Officers at Pejabat Renjer Hutan, Kuala Sepetang for their willingness to help me in this project.

I would like to extent my heartfelt gratitude to Mr. Saad for allowing me to conduct my work in the Forest Survey and Engineering Laboratory and also for offering endless support, advises and help during conduct this project. My deepest appreciation also are extended to all staff of the Faculty of Forestry, UPM, my helpful friends and coursemates for their help and support.

Last but not least, I would like to express my appreciation to my parents and brother for their enormous support and encouragement during this project. A great thanks to my beloved friends, Muhammad Syafiq bin Yahya, Syafiq bin Abdul Razak, Iqbal Putut, Noor Shaila Sarmin, Shamsul and especially to Nur Ainina Khairunnisa binti Othman that help me in succeeding in my project.

I certify that a Thesis Examination Committee has met on _____ to conduct the final examination of Muhammad Ekhzarizal on his thesis entitled "**Estimation of Aboveground Biomass and Carbon Stocks in Matang Mangrove Forest Reserve Using Allometry and Remote Sensing Technique**" in accordance with the Universities and University College 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 Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature : _____
Name of Chairman of Supervisory Committee : Associate Professor Dr. Mohd Hasmadi bin Ismail

Signature : _____
Name of member of Supervisory Committee : Dr. Mohd Roslan bin Mohd Kasim

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LIST OF ABBREVIATIONS

POC	Particulate Organic Carbon
CDM	Clean Development Mechanism
REDD+	Reduced Emissions from Deforestation and Degradation
UNFCC	United Nations Framework Convention on Climate Change
NDVI	Normalised Difference Vegetation Indices
SAVI	Soil Adjusted Vegetation Indices
GEMI-NDVI	Global Environment Monitoring Index-NDVI
GNDVI	Green Normalized Difference Vegetation Index
NIR	Near Infrared
GHG	Green House Gasses
AGB	Aboveground Biomass
SPOT	Systeme Probatoire d'Observation de la Terre
MACRES	Malaysian Centre for Remote Sensing
DN	Digital Number
MMFR	Matang Mangrove Forest Reserve
RMSE	Root Mean Square Error
DBH	Diameter at Breast Height
R^2	Coefficient of determination

CHAPTER 1

INTRODUCTION

1.1 General background

Mangrove forest is defined as a forest of salt-tolerant topical shrub where the mangrove trees are lined with tidal estuaries that are covered by the sea at the high tide (Ibrahim et al., 2015). Mangrove as a shelter that secure most of the land from disaster like strong storms or tsunamis (Mitch and Gosselink, 2007; Giesen et al., 2007; Alongi, 2009) where as a place for better improvement in water quality, fish feeding, preserve a shelter for fish and shellfish. Malaysia is a well known country in Asian region that is dense and well management of mangrove forest found along the coastal line that is a part of the country (Raza et al., 2013). Mangrove area covers of about 645, 852 ha which encompasses of 2% from the whole national land area (Giri et al., 2011). According to Mohti et al. (2014), the total 1.7% of this national land is from mangrove area which is the total of estimated area only 566, 856 ha. This showed that mangrove area in Malaysia is diminishing. West Malaysia (Peninsular Malaysia) possess 99, 767 ha while East Malaysia (Sabah and Sarawak) for about 467, 089 ha. However, mangroves which found in Southest Asia's are still the best developed and most species diserved all over the world (Giesen and Wulffrat, 2007; Hutchison et al., 2014; Richards and Friess, 2016).

A total of 268 plant species have been recorded in Southeast Asian. Mangroves are placed in the coastal boundary and act as carbon pools that efficiently absorb carbon (Patil et al., 2014). Mangrove soil could store in a large amount of carbon compared to other forest types like tropical forest, temperate forest, boreal forest and tropical savannas due to the sediment presence (Tateda, 2005; Patil et al., 2014). Soil also acts as a "sponge" for carbon pools and studies found that the average of carbon storage of mangrove is five times larger than other forest types in the world. Jennerjahn and Ittekkot (2002) reported that mangrove forest will release the excessive carbon of about 10-11% to the water while about 12-15% to the sediments. Mangrove are well known for their high carbon accumulation, with reports Warehouse above 1 000 MgC/ha (Donato et al., 2011). Thus, mangroves play as an important role in reducing climate change by taking carbon dioxide (CO_2) gases out of the atmosphere (Boer et al., 2014; Chen et al., 2016).

Van der Welf el al. (2009) expressed that the land use change had contributed to around 8-20% of CO_2 discharged every year that regularly happened in the tropical forest. With the establishment of one charity namely Reduced Emissions from Deforestation and Degradation (REDD+) at international level which gave the guidelines in order to reduce the impacts on climate change (Cohen et al., 2013). The aim for this organization is to reduce the emission of CO^2, conserve forest and sustain forest structure by put economic values namely carbon credits. A study from Siikamaki et al. (2012) reported that uncontrolled logging activities could be reduced indirectly from several methods and could balance the capacity for carbon mangrove storage. An involvement of REDD+ under United Nations Framework Convention on Climate

Change (UNFCC) association strictly emphasize on following some of methods for forest carbon estimation which is accurate and had been fixed.

Wood density is the main physical element for stand trees and also possesses the porosity, resistance and chemical composition of the cells (Noguiera et al., 2005). Wood density is considered as important parameter for biomass estimation with the using allometric equation while estimating carbon stock by using conversion factor (Komiyama et al., 2005; Santini et al., 2012). Studies on biomass of mangrove tree composition are very important for describing a change in global or regional climate patterns. Carbon removal, production and storage can be derived through biomass estimation by using allometric equations (Komiyama et al., 2005) derived from forest inventories while the conversion factor in order to estimate the amount of carbon stock (Hirata et al., 2012). The estimation of carbon stocks was derived from the amount of biomass by using conversion factor. Results was compared with the destructive methods from Hazandy et al. (2013). The estimation of biomass in mangrove forest with non-destructive method will be heavily depended on the allometry model where the diameter tree and wood density is needed and had been used as variables (Brown, 1997; Brown, 2002; Eskil et al., 2016). There were a few of allometric equations on every tree species for the estimation of aboveground biomass (Clough and Scott, 1989; Komiyama et al., 2005). Therefore, the common allometric equations had been developed for mixed tree species in mangrove forest. This will not take longer time to get the result of aboveground biomass compare with the using tree species-specific equations because there was variety species in mangrove forest. According to Komiyama et al. (2005) and Lupembe (2014), the allometry model is considered as a powerful tool for the estimation of tree biomass in different types of species for mangrove tree while the amount of carbon stock could be estimated by using conversion factor.

Nowadays, the using of remote sensing technique is very important in order to provide message or information about the land use cover and land use change detection for a large area. This techniques had been widely used for investigating in some land use or cover and still developing since the past few centuries (Nelson et al., 1998; Zheng et al., 2004; Mukkonen and Heiskanen, 2005; Wulder et al., 2008). There were many ways to estimate and predict the biomass tree by using remote sensing data. Many studies were used regression analysis as a role model for biomass estimation (Dong et al., 2003; Zheng et al., 2004; Rahman et al., 2005; Muukkonen and Heiskanen, 2005).

The expansion in the using of remote sensing technique for mangrove mapping and monitoring is highly beneficial for sustain forest ecosystem for a long period of time (Kongwongjan et al., 2013). Satellite imagery is one of the commonly tools being widely used for mangrove monitoring because its low cost (Vaiphasa et al., 2005; Kongwongjan et al., 2013). Normalized Difference Vegetation Indices (NDVI) is a well known model and has been widely used in order to estimate biomass tree (Tucker, 1979; Gitelson et al., 1996; Christiano et al., 2014; Sweet et al., 2015). This is because NDVI had proved a well detection on stand trees through canopy (Tucker, 1979; Saliola, 2014). Thus, this study will select NDVI as one of the several list provided in vegetation indices to estimate biomass tree because it could probably shows that the

vegetation variable like leaf area index, canopy cover and chlorophyll concentration were very good in the reflection towards the red and NIR band.

1.2 Problem statements

Index reading for the releasing of greenhouse gasses has achieved 15 until 25% due to disposal and forest logging which produces 1-2 billion tonnes carbon each year since 90s (Ramankutty et al., 2007). According to Ruesch and Gibbs (2008), combination between tropical tropical and sub-tropics forest can reach for about 430 billion carbon tonnes, while boreal and temperate zone region stores totally of 34 billion tonnes and 33 billion tonnes respectively. Every developing countries should manage the mangrove forest very well because they could release the climate change into critical level. Therefore, international countries where are fast developing and large industris entitled to be imposed payments to REDD+ programme if produce greenhouse gasses.

In Malaysia, mangroves face serious threats from development pressures and forest degradation due to timber extraction activities. Because of these factors, there has been a growing need for the intensification of conservation and rehabilitation efforts. Mangroves can be managed to produce carbon offsets, either by sequestering carbon by growing mangroves or by avoiding emissions by avoiding mangrove ecosystem degradation (Lovelock and McAllister, 2013). The estimation of AGB by using common allometric equation for every tree individual need parameters like DBH value and the selection of wood density based on tree species is very important. However, a proper value for wood density were derived from the Global Wood Density database in order to estimate the AGB for individual tree.

Whilst much attention has recently been given to the opportunities allometric equation is often used for many studies to calculate the amount of biomass tree due to approximations that very good as almost the same with the using destructive sampling method. Previous studied had proved that with the using of common allometric equations will have some small error and challenging (Chave et al., 2005; Molto et al., 2013). Factor challenging is because of the environmental conditions which could cause difficulties while collecting the sampling. Combination between measured system and remote sensing technique is very important for the estimation more accurately for aboveground biomass, carbon stock, greenhouse gasses (GHG) and land use change (Kiyono et al., 2011). Heumann (2011) claimed that nowadays photography aerial usage and high resolution image like Landsat and SPOT are very important in mapping and assessment towards mangrove swamp. This could be provable that with the use of aerial photography is better in detection toward identifications of tree species but mapping could be used for small area compared to high resolution image.

In general robust estimates of forest biomass and carbon stocks are crucial in order to constrain uncertainties in regional and global carbon budgets and predictions of climate change made using earth systems models. The estimates are also a key requirement for international for international forest based climate change mitigation strategies such as Reducing Emissions from Deforestation and Forest Degradation (REDD+). Acoording to Stocker (2014) above-ground biomass (AGB) is one of five forest carbon pools

which is measurable and reportable for forest carbon projects operating under existing voluntary or future international compliance carbon markets such as REDD+. Providing estimates of forest AGB which are accompanied by an appropriate measure of the associated uncertainty is a key requirement for REDD+ Measurement, Reporting and Verification (MRV) programs (Maniatis and Mollicone, 2010). Furthermore, much of the uncertainty in remote sensing derived estimates of AGB is due to the uncertainty in the ground-based AGB estimates ('ground truth' data) used to calibrate remote sensing algorithms (Ahmed et al., 2013). Therefore, it is essential to estimates the amount of AGB accompanied by a realistic estimate of the uncertainty in order to constrain the uncertainties involved with remote-sensing based approaches to large-scale monitoring of biomass dynamics (Venter and Koh, 2012). In fact , REDD+ envisages to achieve CO_2 emissions reductions, forest conservation and sustainable development by placing an economic value on forest carbon storage and facilitating the transfer of funds from developed to developing nations through international trade in carbon credits.

1.3 Aims and objectives

The aims of this study is to investigate the usefulness of remote sensing technique in assessing the above-ground biomass and carbon stocks in Mangrove Forest Reserve in Matang, Perak. The specific objectives are:

i. To quantify the above-ground biomass and carbon stocks by using allometry model.
ii. To calculate and map the above-gound biomass and carbon stocks using four vegetation indices from SPOT-5 imagery.
iii. To improve the biomass estimate of direct method by using integration model.

1.4 Organisation of the thesis

This thesis is presented in five chapters. The organisation as below:

Chapter 1 describes the research background, problem statement, aims and objectives, and research design of the study. This introductory chapter also explains the global climate balance which relate to mangrove forest in Peninsular Malaysia and precision of biomass measurements.

Chapter 2 reviews and explores the literature reviews which briefly describes in different techniques for the estimation on biomass and carbon stocks in mangrove forest such as field measurements, modelling in remote sensing and the potential of satellite imagery in carbon credits.

Chapter 3 presents a materials and methods. This chapter describes about measuring above ground biomass and optical image from satellite image. The measuring sampling design explains the field sampling, plots establishment, species composition, and the

equipments had been used while collecting the sample data. The estimation on above ground biomass for each stand trees with the using allometric equation and conversion factor. The study area also described in terms of its texture of soil, climate and vegetation.

Chapter 4 explain about the result and discussion for sampling data and optical image data. Several types of statistics had been used in this topic which are pearson correlation, normality test and regression analysis to test the validity of this data. Every decision will be discussed and compared with the previous studies which is related to this study. Through this, the methods which were used could be proved its validity and also could be used for the future research and further development.

Chapter 5 Lastly, chapter 5 will review all the results and concludes this research study. Besides, it also include the recommendations for the future research and development efforts on the potential use on SPOT 5 image and other optical images in estimating the aboveground biomass for mangrove forest in Malaysia region.

1.5 Limitation and Scope of the study

Perak state is a well known of very systematic mangrove forest management since 1906 and has been gazetted as permanent forest reserve. The area is easily assess by team members for collecting the samples. The study only covered for Kuala Sepetang (South), Matang Mangrove and the sampling are limited to five parameters which are dbh, tree height, wood density and tree species. The study also has been conducted to examine the capability of SPOT 5 image in estimating the aboveground biomass of mangrove forest. Only four vegetation indices (VI's) were used and selected for this study in order to correlate with measured biomass by using regression analysis. In regression analysis, some methods were applied. Then the method was upgraded based on previous studies, which has designed to increas the quality of the image and improve the accuracy for biomass estimation.

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