UNIVERSITI PUTRA MALAYSIA

STRUCTURE, BIOMASS AND CARBON ASSESSMENT OF CHRONOSEQUENCE REHABILITATED TROPICAL FOREST STANDS

ROLAND KUEH JUI HENG

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DOCTOR OF PHILOSOPHY
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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

STRUCTURE, BIOMASS AND CARBON ASSESSMENT OF CHRONOSEQUENCE REHABILITATED TROPICAL FOREST STANDS

By

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April 2013

Chairman : Professor Dato' Nik Muhamad Ab. Majid, PhD

Faculty : Agriculture and Food Sciences (Bintulu)

Global forest area loss and degradation are some of the major global environmental issues. These issues have elevated the role of the remaining secondary and rehabilitated forests in providing goods and services to mankind. The secondary and rehabilitated forests have the potential to assimilate and store relatively large amount of biomass and carbon. Such information is rather limited in rehabilitated forest especially for tropical region. The objectives of this study were to: (i) determine biomass distribution of a rehabilitated forest, (ii) develop allometric biomass equation, and (iii) estimate carbon fixed in the trees and soil of a rehabilitated forest. The study site was at the UPM-Mitsubishi Corporation Forest Rehabilitation Project, UPM Bintulu Sarawak Campus, Bintulu, Sarawak. The research was conducted in 2009. Plot of 20 x 20 m was established each at 19-(Plot 1991), 10-(Plot 1999), one-

year-old (Plot 2008) rehabilitated forests and ± 23-year-old natural regenerating secondary forest (Plot NF).

Modified allometric equations were used to estimate the biomass and carbon distribution and storage. Analyses showed that the contribution of tree component biomass/carbon to total biomass/carbon was in the order of main stem > branch > leaf. The total above ground biomass for the rehabilitated forest ranged from 0.1-118.9 t/ha compared to natural regenerating secondary forest of 134.2 t/ha while the total above ground carbon was 0.1–54.0 t/ha and 61.0 t/ha, respectively.

The above ground storage (above ground biomass and standing crop litter) was about 70-72% of the total biomass and 64-67% of total carbon in 19-year-old rehabilitated and natural regenerating secondary forests, while 10- and one-year-old rehabilitated forests were 42% and 10% of the total biomass, 36% and 8% of the total carbon, respectively. The below ground storage was about 28-30% of the total organic matter and 33-36% of the total carbon in 19-year-old rehabilitated and natural regenerating secondary forests, while for 10- and one-year-old rehabilitated forests were 58% and 90%, 64% and 92%, respectively.

The above ground forest restored the soil organic matter and soil carbon in the rehabilitated forest and this provides organic matter inputs in the form of above and below ground litter. The variations of the biomass and carbon storage were contributed by the differences in the forest structure, microclimatological and soil conditions. These indicate the different successional stages at the study plots.

Forest structural analysis showed that the rehabilitated forest performs better in terms of structural characteristics compared to the adjacent natural regenerating secondary forest. However, the rehabilitated forest exhibited climax species community despite having lower species diversity. Microclimatological analyses showed that the microclimatological conditions inside the forests were less extreme and more humid compared to the open space. In addition, soil analyses showed that the acidic soils in all the study sites were low in nutrients and infertile.

The stressful environment created through high density tree planting has promoted accelerated performance of the physical tree characteristics. This has contributed to the higher biomass and carbon storage. Older rehabilitated forest of 19 years old had total above ground biomass and carbon storage comparable to the natural regeneration secondary forest. This reaffirms the need for human intervention in rehabilitating degraded forest areas through tree planting initiatives. It can be concluded that forest rehabilitation programme showed potential in facilitating the recovery of biomass and carbon storage.

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

PENILAIAN STRUKTUR, BIOJISIM DAN KARBON SECARA KRONOJUJUKAN DI DIRIAN HUTAN TROPIKA TERPULIH

Oleh

ROLAND KUEH JUI HENG

April 2013

Pengerusi : Profesor Dato' Nik Muhamad Ab. Majid, PhD

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Kehilangan dan degradasi hutan sejagat adalah antara isu persekitaran sejagat yang utama. Dengan isu tersebut, ia telah meningkatkan peranan hutan sekunder dan terpulih dalam menyediakan produk dan perkhidmatan kepada manusia sejagat. Hutan sekunder dan terpulih mempunyai potensi untuk mengasimilasi dan menyimpan sebahagian besar biojisim dan karbon. Maklumat sedemikian adalah terhad di hutan terpulih terutamanya di kawasan tropika. Objektif kajian ini adalah untuk: (i) membandingkan pengagihan biojisim di hutan terpulih, (ii) membangunkan persamaan alometrik biojisim, dan (iii) menganggarkan karbon terikat dalam pokok dan tanah di hutan terpulih. Tapak kajian adalah di Projek Pemulihan Hutan UPM-Mitsubishi Corporation, UPM Kampus Bintulu Sarawak, Sarawak. Kajian ini dijalankan pada 2009. Plot bersaiz 20 x 20 m telah ditubuhkan setiap satu di hutan terpulih berumur 19 (Plot 1991), 10 (Plot 1999), satu tahun (Plot

2008) dan hutan sekunder beregenerasi secara semulajadi berumur ± 23 tahun (Plot NF).

Modifikasi perhubungan alometrik digunakan untuk menganggarkan pengagihan dan takungan biojisim dan karbon. Analisa menunjukkan pembahagian biojisim/karbon pada komponen pokok kepada jumlah biojisim/karbon adalah dalam susunan batang utama > dahan > daun. Jumlah biojisim atas tanah untuk hutan terpulih adalah dalam julat 0.1-118.9 t/ha berbanding di hutan sekunder beregenerasi secara semulajadi dengan 134.2 t/ha manakala jumlah karbon atas tanah, masing-masing adalah 0.1-54.0 t/ha dan 61.0 t/ha.

Takungan di atas tanah (biojisim atas tanah dan sarap dirian tanaman) adalah 70-72% daripada jumlah biojisim dan 64-67% daripada jumlah karbon di hutan terpulih berumur 19 tahun dan hutan sekunder beregenerasi secara semulajadi, manakala hutan terpulih berumur 10 dan satu tahun, masing-masing adalah 42% dan 10% daripada jumlah biojisim, 36% dan 8% daripada jumlah karbon. Takungan di bawah tanah adalah 28-30% daripada jumlah bahan organik dan 33-36% daripada jumlah karbon di hutan terpulih berumur 19 tahun dan hutan sekunder beregenerasi secara semulajadi, manakala hutan terpulih berumur 10 dan satu tahun, masing-masing adalah 58% dan 90%, 64% dan 92%.

Hutan di atas tanah memulihkan bahan organik tanah dan karbon tanah di hutan terpulih yang mana ia adalah input bahan organik dalam bentuk sesarap di atas dan bawah tanah. Variasi dalam takungan biojisim dan karbon disumbangkan oleh perbezaan keadaan pada struktur, mikroklimatologi dan tanah hutan. Ini menandakan peringkat sesaran yang berbeza di plot kajian.

Kajian struktur hutan menunjukkan prestasi lebih baik dari segi ciri-ciri struktur di hutan terpulih berbanding dengan hutan sekunder beregenerasi secara semulajadi. Hutan terpulih menunjukkan komuniti spesies klimaks meskipun mempunyai kepelbagaian spesies yang rendah. Kajian mikroklimatologi menunjukkan mikroklimatologi di dalam hutan adalah kurang ekstrim dan lebih lembab berbanding dengan kawasan terbuka. Tambahan lagi, kajian tanah menunjukkan tanah berasid di semua tapak kajian yang mana ia kekurangan nutrien dan kurang subur.

Persekitaran yang tertekan wujud daripada penamanan pokok pada densiti tinggi meningkatkan prestasi ciri-ciri fizikal pokok. Ini menyumbang kepada takungan biojisim dan karbon yang lebih tinggi. Hutan terpulih yang tua seperti yang berumur 19 tahun mempunyai jumlah takungan biojisim dan karbon atas tanah yang setara dengan hutan sekunder beregenerasi secara semulajadi. Ini mengesahkan keperluan campur tangan manusia dalam memulihkan kawasan hutan yang telah degradasi melalui initiatif penamanan pokok. Kesimpulannya, program pemulihan hutan menunjukkan potensi dalam membantu pemulihan takungan biojisim dan karbon.

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I certify that a Thesis Examination Committee has met on 18 April 2013 to conduct the final examination of Roland Kueh Jui Heng on his (or her) thesis entitled "Structure, Biomass and Carbon Assessment of Chronosequence Rehabilitated Tropical Forest Stands" 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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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

ROLAND KUEH JUI HENG

Date: 18 April 2013

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CHAPTER 1

INTRODUCTION

1.1 Background

In Asia, forests are important as part of the cultural landscape in traditional societies, because of dependence on forest based resources for livelihoods (Ramakrishnan, 2007). In tropical forest countries, anthropogenic activities like logging and agricultural activities in forests are common. It was reported by the United Nation Food and Agriculture Organization (FAO) that between 2000 and 2006, most Asia-Pacific countries experienced a net loss of forest area. However, forest area in Southeast Asia has the largest decline. It has annual net loss of forests of more than 2.8 million hectares per year. The highest ranked was in Indonesia, followed by Myanmar, Cambodia, the Philippines, Malaysia, and the Democratic People's Republic of Korea (FAO, 2007).

FAO also reported that between 2000 and 2010, 13 million hectares of forests in the world were converted to other land use or lost, while the remaining global forest contributed 36% of primary forest, 57% of naturally regenerated forest and 7% of planted forest (FAO, 2010). This has elevated the role of the remaining forest such as secondary, regenerating and rehabilitated forest in providing and maintaining biodiversity conservation and ecological functions such as soil protection and carbon sequestration (Lindholm and Berg, 2005) and societal benefits.

Forests play a prominent role in the global carbon cycle and their importance to greenhouse effect is well known. The ability to sequester carbon dioxide in the atmosphere through photosynthesis enables green plants to play significant role in carbon sequestration. Forests should no longer be viewed as only a *green gold mine* but also as a provider of tangible and intangible products and services. Carbon storage in the world's forests was estimated at 289 gigatones (Gt) in 2010. On the other hand, forest carbon stock decreased by 0.5 Gt annually from 2005 to 2010, due to the decline in forest area (FRA, 2010). Therefore, remaining forest (mainly the natural regenerating secondary forest, forest plantation and rehabilitated forest) could help to increase carbon stock.

The signing of the Kyoto Protocol on the February 16, 2005 (Hwan, 2005) marked a global effort to mitigate the effects of greenhouse gases emissions which contribute to global warming (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons). At the Copenhagen Climate Change Summit in 2009, developed nations renewed their commitment to the Kyoto Protocol and targeted these nations to reduce their greenhouse gas emissions to at least 40% compare to 1990 by 2020 (Netto, 2009). Malaysia is reported to be committed to a carbon reduction of 40% by 2020 with assistance from the developed nations (NRE, 2009). Malaysia was also reported to be the third highest carbon emitter in South East Asia with 187 million tonnes of carbon emission in 2006 or 7.2 t CO_2 per capita (Netto, 2009).

Under the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol allows three market-based mechanisms namely: emissions trading known as carbon market, the clean development mechanism (CDM) and joint implementation (JI). With economic and monetary values being attached to carbon sequestration, there is an increased scrutiny of techniques for estimating above ground biomass (Montagu *et al*., 2005). Carbon dioxide is fixed by plants as organic matter (known as biomass). Most studies suggested that about 45 to 50% of biomass is carbon (Basuki *et al*., 2009; Brown, 1997; Chan, 1982). Hence, forest biomass is a potentially large carbon pool that could be added to the atmosphere, as carbon dioxide if the forest is cleared or burned.

Intensive derivation of biomass regression models in Malaysia started as early as 1978 by Kato *et al*. (1978) at Pasoh Forest Reserve, Negeri Sembilan, Malaysia. Most of these regression models were derived from ecological study plots, designed to describe local forest structure only. Hence, study plots were not truly randomly located not representative (Brown and Lugo, 1982b). Therefore, such studies are suitable for studying the local forest and may not be representative of the overall forest landscape (Brown *et al*., 1989). Localized models may therefore improve estimates of biomass and carbon stock for the Sarawak's forest. This will aid forest managers to calculate the amount of carbon dioxide that can be removed from the atmosphere by regrowth, rehabilitated or naturally regenerating forest.

1.2 Justification of Study

Carbon cycle in the terrestrial ecosystem occurs when atmospheric carbon is used in photosynthesis to create new plant material. This process transfer large amounts of carbon from one pool (the atmosphere) to another (plants). In plants, the woody stems have the ability to store large amounts of carbon because wood is dense and trees can grow large. CO_2 is released back into the atmosphere through respiration. Carbon from dead plant material can be incorporated into soils and decomposed by soil microbes. This will release the carbon back to the atmosphere. Some of the organic matter that became buried in deep sediments would slowly transformed into deposits of coal, oil and natural gas. Generally, the carbon pools can be divided into four major pools namely (i) above ground biomass, (ii) below ground biomass, (iii) deadwood and litter, and (iv) soil carbon pool which consists of inorganic carbon and soil organic carbon (Rodeghiero *et al*., 2010; Lal, 2008; MacDicken, 1997).

The carbon pools are interconnected with the fluxes. Based on the report by Lal (2008), the biotic pool (which consists of wood and non wood), has wood storage of 400-500 Pg while non wood of 100-150 Pg, while the fluxes reported for respiration was 60 Pg/year while the gross primary productivity was 120 Pg/year. The pedologic pool (which consists of soil organic/inorganic carbon, litter and peat) which has soil organic carbon storage of 1,550 Pg, soil inorganic carbon of 950 Pg, litter of 40-80 Pg and peat of 150 Pg. The fluxes reported for decomposition was 60 Pg/year, soil erosion was 1.1 Pg/year and weathering was 0.2 Pg/year.

The issues related to forest degradation and loss would affect these carbon pools and fluxes. The wide areas to cover would be limited by the financial constraints, time and possible technical aspects. Therefore, the main focus of this study would be the tree biomass and carbon in the above ground carbon pool and the soil organic matter and carbon in the below ground carbon pool. With the efforts to rehabilitate degraded forest areas, it would be interesting to assess how forest rehabilitation can restore the biomass and carbon storage in degraded areas.

Rehabilitation on degraded areas has the potential to enhance carbon storage through accumulation of biomass and soil carbon (Silver *et al*., 2004; Silver *et al*., 2000; Ritcher *et al*., 1999). Hence, facilitating rehabilitation activities can be one of the effective ways in managing carbon (Montagnini and Porras, 1998). Forest rehabilitation is not only meant to restore degraded forest area but also as a method that can restore degraded soil resulting from deforestation. The Miyawaki's method to rehabilitate degraded forest areas applies high density tree planting of indigenous species (potential natural vegetation of the area). Weeding is done until 3 years after planting and in the subsequent years, the seedlings grow independently to survive (Miyawaki, 2011; Miyawaki *et al*., 1993; Miyawaki, 1999).

Lugo *et al*. (2004) found that above ground biomass and soil carbon accumulation of rehabilitated tropical forests is related to: (i) age, (ii) climate, and (iii) previous land use. Forests rehabilitated on degraded sites accumulated less above ground biomass than those on agricultural land. Rates of above ground biomass accumulation in rehabilitated forests were low in the first 10 years of forest establishment. However, other reports suggest that the above ground biomass increases at a higher rate during the first 20 years of forest establishment than during the subsequent 60 year period (Silver *et al*., 2000). Therefore, regenerating forest accumulates carbon at a rapid rate and can serve as a net sink for CO_2.

It was also reported that the rate of forest dynamics especially ecological processes peak in the early decades of forest rehabilitation and decline at maturity (Lugo *et al*. (2004). These ecological processes are such as litter production, biomass production, soil carbon accumulation, nutrient accumulation (Lugo *et al*., 2004), ameliorating microclimatic conditions and providing shelter and structural complexity for wildlife (Silver *et al*., 2000). Species composition dynamics and canopy closure also influence the rate of primary productivity of older rehabilitated stands. Species composition dynamics also influences the dynamics of the nutrients. The ratio of primary productivity to biomass is high in young rehabilitated forests and low in mature stands. The ratio is low when past land use has little effect on biomass accumulation, and high when past land use has reduced biomass accumulation. This is due to different rates of litterfall in rehabilitated forests. This facilitates soil restoration by circulating more nutrients and biomass per unit biomass accumulated in the forest stand (Lugo *et al*., 2004).

As for soil carbon storage, it averages 60 t/ha in the first 20 years and peaks (74 tC/ha) during the subsequent 20-100 years of forest rehabilitation (Silver *et al*. 2000). This is mainly influenced by past land use. Generally, sites that were deforested, but not managed prior to forest re-establishment tend to accumulate soil carbon at a faster rate than ex-agricultural sites (Silver *et al*., 2000). In addition, soil carbon accumulation is highly species-dependent, due to differences in litter production, litter quality, microclimatic changes and changes in edaphic conditions (Silver *et al*., 2000; Lugo and Brown, 1993).

Forest rehabilitation was suggested as one of the strategies to achieve above and below ground carbon sequestration through improving biomass and soil carbon storage (Silver *et al*., 2000; Brown, 1998). There is lack of information on biomass and carbon storage in the tropical region especially on rehabilitated forest. There are several reasons related to this issue, among others are the labour intensive, expensive and time consuming (Avitabile *et al*., 2008) in conducting field work. In addition, local issues related to accessibility to the forest area as forest belongs to the government and requires clearance for such research to be conducted. In addition, there is also lack of local expertise as reflected by the limited published literatures such as by Tangki and Chappell (2008), Mat-Salleh *et al*. (2003), Lim and Mohd. Basri (1985).

The need for such research arises in the carbon inventory to assess the changes in carbon stocks. The monitoring on the above and below ground biomass, litter, dead wood and soil organic carbon are required. This will determine the sequestration potential and emissions in an area (Elizabeth and Norini, 2010). The most common methods to determine above ground forest biomass are the combination of forest inventories with allometric tree biomass regression models and remote-sensing techniques (Houghton, 2005; Brown, 2002; Houghton *et al*., 2001). Hence, such data is important for managing forested area for reducing and mitigating CO_2 emission (Van Breugel *et al*., 2011).

Different age stands have different capacity to sequester carbon. This information facilitates quantification of biomass/carbon storage and sequestration of rehabilitated forests. The scope of this research covers the aspect of the recovery of the above ground tree biomass and carbon. In addition, below ground soil organic matter and carbon was also estimated. Such information would indicate the recovery of the biomass and carbon storage after forest rehabilitation activities were carried out on degraded forest areas. Hence, this research would provide better understanding of biomass and carbon storage in different aged stands of rehabilitated forests.

1.3 Objectives

In view of a gap in knowledge of biomass and carbon storage in rehabilitated forest in Sarawak, this study estimated standing tree biomass and carbon of a rehabilitated forest. Information on different age stands of the rehabilitated forest will provide insight into the distribution and storage of biomass and carbon. The specific objectives of this study were to:

i) Compare biomass distribution of a rehabilitated forest at different stand age and site conditions. This was also to provide an indication of the forest recovery status.

ii) Develop allometric biomass equation of a rehabilitated forest which can assist forest managers to estimate accumulation of biomass. This provides information on the carbon fixed at different age stands of the rehabilitated forest.

iii) Estimate carbon fixed in trees and stored in the soil. This information provides better understanding of the carbon storage at different age stands of the rehabilitated forest.

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Roland Kueh Jui Heng was born on the August 16, 1973, in Kuching Division, Sarawak, Malaysia. He received his secondary education at SMB Sacred Heart, Sibu Division, Sarawak, Malaysia and completed in 1990. He later continued his study at Universiti Putra Malaysia where he pursued the Diploma in Agriculture in Bintulu Campus, Sarawak. A year later, he was promoted to undertake the Bachelor of Science in Forestry in Serdang Campus, Selangor, Malaysia and earned his Bachelor degree in 1996. Upon completion of his first degree, he enrolled in for his Master's degree programme at the same university and earned his Master of Science (majoring forest ecology) in 2000. He was employed in various logging company and local forest authorities before he was offered the post of a tutor in Universiti Putra Malaysia Bintulu Sarawak Campus in 2004. In 2006, he was promoted to the post of a lecturer and in 2009, he enrolled for his Doctor of Philosophy programme at the same university under the sponsorship of the Ministry of Higher Education and a research grant from the UPM-Mitsubishi Corporation Forest Rehabilitation Project.

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