ESTIMATION OF TOTAL CARBON POOLS AND FLUXES IN A SELECTIVE LOGGING FOREST AREA IN TAWAU, SABAH, MALAYSIA

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Penyelia Utama

DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, equations, summaries, and references, which have been duly acknowledged.

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ABSTRACT

The tropical rainforest has a great capability for storing an enormous amount of carbon in its carbon pools and different logging methods affects the vegetation's ability to restore carbon. There is also a growing concern that unsustainable logging methods threaten the forest ecosystem, thus triggering the release of forest carbon into the atmosphere hence contributing to ongoing climate change. This study aimed to investigate the impacts of different logging methods on the soil physicochemical properties, total ecosystem carbon pools, and the soil carbon fluxes in Gunung Rara Forest Reserve, Tawau, Sabah, Malaysia. The two logging methods that were investigated are supervised logging with climber cutting (SLCC), conventional logging (CL), and an unlogged forest, which is a primary forest (PF) that represents the control areas. The size for each plot was 0.36 ha (60 m x 60 m) and each plot was replicated four times resulting in a total of 12 plots. Forest inventory was done to measure the diameter at breast height (DBH) of the standing trees with DBH of more than 10 cm while soil sampling at four different depths (0-10 cm, 10-20 cm, 20-50 cm, and 50-100 cm) was done for soil analysis. Coarse woody debris was measured one meter along the plot boundaries and the organic layer was collected using a 0.25 m^2 sampling frame. The estimation of litterfall production and the soil carbon fluxes were measured by the soil respiration rate annually, from March 2019 to February 2020. The litterfall was collected using 0.25 m^2 litterfall traps while soil respiration was recorded using a Vaisala Hand-Held Carbon Dioxide Meter. Allometric equations were used to estimate the standing tree's and root's carbon pools. The soil samples were analyzed using a Vario Max CN Elemental Analyzer for their carbon content. After 26 years of being logged, the finding shows that there was no significant difference observed in the soil physicochemical properties, total ecosystem carbon pools, and soil carbon fluxes between the different logging methods and the primary forest. The soil in all study areas was found acidic with a range from 3.87 to 4.54 and sand dominated the soil texture with a mean value of up to 71%. The primary forest area still holds the highest total ecosystem carbon pools with 281.82 ± 23.55 Mg C ha^{-1}. Among the logging methods, the supervised logging with climber cutting area holds a slightly higher mean value of total ecosystem carbon pools which is 268.39 ± 9.59 Mg C ha^{-1} compared to the conventional logging area with a mean value of 265.12 ± 14.30 Mg C ha^{-1}. The results also showed that the standing trees and soil carbon pools contributed the most to total carbon pools with approximately 54% and 29%, respectively. On the other hand, the supervised logging with climber cutting area resulted in the highest rate of soil respiration throughout the year with a mean value of 161.75 ± 21.67 mg C m^{-2} h^{-1}, followed by the primary forest area with a mean value of 149.59 ± 12.46 mg C m^{-2} h^{-1}. The conventional logging area resulted in the lowest soil respiration rate with a mean value of 140.54 ± 12.54 mg C m^{-2} h^{-1}. These findings highlight the importance of accurate quantification of the effect of different logging methods on the forest's carbon pools.

ABSTRAK

ANGGARAN JUMLAH SIMPANAN KARBON DAN FLUKS DI DALAM KAWASAN HUTAN PEMBALAKAN TERPILIH DI TAWAU, SABAH, MALAYSIA

Hutan hujan tropika mempunyai keupayaan yang tinggi di dalam menyimpan sejumlah karbon yang besar di dalam simpanan karbonnya dan kaedah pembalakan yang berbeza menjejaskan keupayaan tumbuhan di dalam hutan untuk memulihkan karbon. Terdapat juga kebimbangan yang semakin meningkat terhadap kaedah pembalakan yang tidak mampan yang mengancam ekosistem hutan, sekali gus menyebabkan pembebasan karbon daripada hutan ke atmosfera dan seterusnya menyumbang kepada perubahan iklim yang berlaku pada masa kini. Tujuan kajian ini adalah untuk mengkaji kesan kaedah pembalakan yang berbeza terhadap sifat fisikokimia tanah, jumlah simpanan karbon ekosistem, dan fluks karbon tanah di Hutan Simpan Gunung Rara, Tawau, Sabah, Malaysia. Dua kaedah pembalakan yang dikaji adalah pembalakan diselia dengan pemotongan tumbuhan pemanjat (SLCC), pembalakan konvensional (CL), dan hutan yang tidak dibalak iaitu hutan primer (PF) yang mewakili kawasan kawalan. Saiz bagi setiap plot adalah 0.36 ha (60 m x 60 m) dan setiap plot direplikasi 4 plot menjadikan jumlah plot adalah 12. Inventori hutan dilakukan untuk mengukur diameter pada ketinggian paras dada (DBH) pokok yang mempunyai DBH lebih daripada 10 cm manakala persampelan tanah pada empat kedalaman berbeza (0-10 cm, 10-20 cm, 20-50 cm, dan 50-100 cm) telah diambil untuk analisis tanah. Serpihan kayu kasar diukur satu meter di sepanjang sempadan plot dan lapisan organik dikumpul menggunakan bingkai persampelan berukuran 0.25 m^2. Pengukuran penghasilan penentuan luruhan daun dan fluks karbon diukur menggunakan kadar respirasi tanah selama satu tahun dari Mac 2019 sehingga Februari 2020. Luruhan daun pokok dikumpul menggunakan sebuah perangkap berukuran 0.25 m^2 manakala respirasi tanah direkod menggunakan meter Vaisala Hand-Held Carbon Dioxide. Persamaan alometrik telah digunakan untuk mengganggar simpanan karbon pokok hidup dan akar. Sampel tanah telah dianalisis menggunakan Vario Max CN Elemental Analyzer untuk kandungan karbon. Selepas 26 tahun dibalak, dapatan kajian menunjukkan tiada perbezaan ketara dapat dilihat pada sifat fisikokimia tanah, jumlah simpanan karbon ekosistem, dan fluks karbon tanah di antara kaedah pembalakan yang berbeza dengan hutan primer. Tanah di semua kawasan kajian didapati berasid dengan julat min di antara 3.87 hingga 4.54 dan pasir mendominasi tekstur tanah dengan nilai min sehingga 71%. Kawasan hutan primer masih mempunyai nilai jumlah simpanan karbon ekosistem yang tertinggi dengan 281.82 ± 23.55 Mg C ha^{-1}. Di antara kaedah pembalakan yang berbeza, pembalakan yang diselia dengan pemotongan tumbuhan pemanjat mempunyai nilai jumlah simpanan karbon ekosistem yang tinggi sedikit iaitu 268.39 ± 9.59 Mg C ha^{-1} berbanding dengan kawasan pembalakan konvensional iaitu 265.12 ± 14.30 Mg C ha^{-1}. Keputusan kajian juga mendapati pembalakan diselia dengan pemotongan tumbuhan pemanjat mencatatkan kadar respirasi tanah tertinggi sepanjang tahun dengan nilai min 161.75 ± 21.67 mg C m^{-2} h^{-1}, diikuti kawasan hutan primer dengan nilai min 149.59 ± 12.46 mg C m^{-2} h^{-1}. Pembalakan *konvensional mencatatkan kadar respirasi tanah yang paling rendah dengan nilai min 140.54 ± 12.54 mg C m^{-2} h^{-1}. Dapatan kajian ini menekankan kepentingan penganggaran yang tepat terhadap kesan kaedah pembalakan yang berbeza ke atas simpanan karbon di dalam hutan.*

UMS
UNIVERSITI MALAYSIA SABAH

LIST OF CONTENTS

UMS UNIVERSITI MALAYSIA SABAH

UMS
UNIVERSITI MALAYSIA SABAH

UMS UNIVERSITI MALAYSIA SABAH

CHAPTER 6: RECOMMENDATIONS

UMS
UNIVERSITI MALAYSIA SABAH

LIST OF TABLES

UMS
UNIVERSITI MALAYSIA SABAH

UMS
UNIVERSITI MALAYSIA SABAH

LIST OF FIGURES

UNIVERSITI MALAYSIA SABAH

UMS UNIVERSITI MALAYSIA SABAH

UMS
UNIVERSITI MALAYSIA SABAH

LIST OF ABBREVIATIONS

C	-	Carbon
CH_4	-	Methane
cm	-	Centimetre
CN	-	Carbon Nitrogen
CO_2	-	Carbon Dioxide
FAO	-	Food And Agriculture Organization
FMU	-	Forest Management Unit
FR	-	Forest Reserve
g	-	Gram
$g\ cm^{-3}$	-	Gram Per Cubic Centimetre
GPS	-	Global Positioning System
Gt	-	Gigatonne
ha	-	Hectares
IBM	-	International Business Machines
IPCC	-	Intergovernmental Panel on Climate Change
ITTO	-	International Tropical Timber Organization
IUCN	-	International Union for Conservation Of Nature
m	-	Meter
m^2	-	Meter Square
m^3	-	Cubic Meter
MENR	-	Ministry Of Energy and Natural Resources
Mg	-	Megagram
ml	-	Millilitre
mm	-	Millimetre
^oC	-	Degree Celsius
Pg	-	Petagram
Ppm	-	Parts Per Million
SFD	-	Sabah Forestry Department
SFM	-	Sustainable Forest Management
SFM	-	Sustainable Forest Management

UMS
UNIVERSITI MALAYSIA SABAH

SFMLA	-	Sustainable Forest Management License Agreement
SPSS	-	Statistical Package for Social Sciences
SUAS	-	Swedish University of Agricultural Sciences
TPA	-	Total Protected Areas
UNEP	-	United Nations Environment Programme
USA	-	United States of America
USDA	-	United States Department of Agriculture

UMS
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CHAPTER 1

INTRODUCTION

1.1 Introduction

The tropical rainforest is one of the primary biomes in the terrestrial ecosystem and possesses the most extensive forested area (45%) than other biomes such as boreal (27%), temperate (16%), and subtropical (11%) (FAO, 2020). It provides food, shelter, clean water, and wood to the community that lives in the forest or nearby areas (Sommerville *et al.,* 2021). In addition, the forest has a crucial role in mitigating climate change due to its dual ability to act as the carbon source to the atmosphere and the carbon sink (Stas *et al.,* 2020; Butarbutar *et al.,* 2019).

Globally, from 2007 to 2016, Shukla *et al.* (2019) reported that the agriculture, forestry, and other land use change sectors had contributed approximately 23% of total anthropogenic greenhouse emissions to the atmosphere. While in the tropics, forest degradation is responsible for emitting about 1.9 Pg C per year and 53% of it comes from timber harvesting (Pearson *et al.,* 2017). The unsustainable way of harvesting timber in the forest not only causes damage to the forest's capability to store carbon but also has a significant impact on the soil ecosystem. For example, it could increase soil compaction and temperature, leading to soil erosion and declining soil quality (Zhou *et al.,* 2015).

The standard logging method that has long been implemented in tropical forests is selective logging (Riutta *et al.,* 2021). It is a method where only a commercially valuable timber species that meets a particular diameter value will be harvested from the forest. Selective logging was also considered a Sustainable Forest Management (SFM) practice as it allows people to use the forest resource while

UNIVERSITI MALAYSIA SABAH

maintaining and preserving the forest condition (Gatti *et al.,* 2015). In the early implementation of selective logging in the forest, there were still some damages that can be observed as it was done in an unsupervised manner, well known as conventional logging (Lussetti *et al.,* 2016). This logging method was conducted without proper planning and guidance to the feller and consequently damaging the residual stand (Forshed *et al.,* 2006).

Reduced impact logging (RIL) practice was then developed to improve the previous logging method. However, it is seldom being practised because of its strict guidelines and more expensive compared to the conventional logging method (Lussetti *et al.,* 2019). Ultimately, a more practical system named supervised logging was introduced. This system was carried out more appropriately than the conventional logging method as it involves the directional felling and planned skid trails. The workers also were given detailed instructions before the felling activity was done (Lussetti *et al.,* 2016).

Assessing the effect of different logging methods on the forest carbon pools is crucial as the forest has important role in mitigating the climate change problems. In addition, as the recovery period of biomass and carbon pools depends on the logging intensity, it is crucial to do an accurate quantification on the effect of different logging method on the forest carbon pools in seeking the best forest management practices that can allow us to extract the raw products from forest without causing too much harm on the forest ecosystem (Butarbutar *et al.,* 2019).

It is also one of the critical elements that needs to be included in the Reducing Emission from Deforestation and Forest Degradation in developing countries (REDD+) programme as Malaysia is one of the countries that committed to it under the United Nations Framework Convention on Climate Change (UNFCCC) through Intergovernmental Panel on Climate Change (IPCC) (Omar *et al.,* 2015). The information from this measurement is important to acknowledge the contribution of forest management practices that has been applied in tropical forest to the global carbon budget and its share in the REDD+ program.

UMS
UNIVERSITI MALAYSIA SABAH

1.2 Problem Statements

Forest has a vital role in the global carbon cycle as it could act as the carbon sink and the source of atmospheric carbon (Butarbutar *et al.,* 2019). Unfortunately, the increasing demand for wood products, energy, conversion into agricultural lands, and development projects is causing the forest to suffer a rapid deforestation rate globally (Omar and Misman, 2018; Thapa *et al.,* 2015). Many research publications reported that deforestation and forest degradation caused by unsustainable logging contributed from 8% to 15% of the total global greenhouse gases (GHG) back to the atmosphere and subsequently caused global warming (Butarbutar *et al*., 2019; Stas *et al*., 2020; Raihan *et al*., 2021). Almost 53% of this total annual emission comes from timber harvesting, and the remaining percentage comes from wood fuel harvest and forest fires (Pearson *et al*., 2017; Butarbutar *et al*., 2019).

The logging activity in the forest also could affect the soil respiration rates due to the disturbance in the litter amount and changes in environmental factors such as soil moisture and temperature (Propa *et al.,* 2021; Takada *et al.,* 2015). About 98 Pg of carbon was released into the atmosphere through soil respiration, at which a rate that is ten times bigger than the emission from the combustion of fossil fuels (Zhang *et al.,* 2020). Enhancing the knowledge of the impacts of the anthropogenic activity on the spatial variabilities of soil respiration rates is crucial to the carbon balance research and to curtail the rise of carbon dioxide value in the atmosphere (Tian *et al.,* 2019; Hosea *et al.,* 2017)

1.3 Justification

Knowledge information on the impacts of this logging method on carbon pools and fluxes are still considered scarce in some regions, specifically here in Sabah, Malaysia. The information is essential to seek the best management practices that could satisfy both the economic demands on forest timber and the need to conserve the ecosystem services. Many studies on the logging area focused on its impact on timber regeneration after logging, fire susceptibility, light availability, and ground damage.

For example, the previous studies made by Lussetti *et al.* (2016) found that the ingrowth and survival rate of the pioneer species in the supervised logging has reduced up to 50% compared to the conventional logging method. While Forshed *et al.* (2008) reported that combining these logging methods with a climber cutting treatment has significantly improved the total net basal area growth to 6.4 m^2 ha^{-1} compared to the uncut area which is 3.3 m^2 ha^{-1}.

On the other hand, Omar *et al.* (2015) in their study on assessing carbon pools at different level of forest disturbances in dipterocarp forests of Peninsular Malaysia shows that the production forest area that has been logged within less than 10 years has a significantly lower amount of total carbon pools compared to the protection forest due to the recent removal of larger trees.

Thus, research on the effect of selective logging (supervised and conventional logging) towards the forest's capability to sequester carbon from the atmosphere and to store the carbon, especially here in Sabah, Malaysia, is very much in need. The current situation where the demand for wood products does not show any sign of depleting anywhere soon is putting tremendous pressure on the wood-based industry. The findings from this research are expected to fill the knowledge gap from the previously mentioned studies. Other than that, the result from this study could provide insightful information that could benefit related organizations (government or non-government) to decide which actions are best for their target area. Lastly, the collected data could also be a guideline for future researchers to better understand forest carbon pools and the effect of logging activities on them.

1.4 Objectives

The general objective of this research was to ascertain the logging method that has the most negligible impact on the capability of carbon pools to store carbon. Meanwhile, the specific objectives for this study were:

1. To determine the soil physico-chemical properties of the forest 26 years after being logged.