



UNIVERSITI PUTRA MALAYSIA

***EFFECT OF LOGGING OPERATIONS ON SOIL CARBON STORAGE OF
A TROPICAL PEAT SWAMP FOREST IN SARAWAK, MALAYSIA***

ANTON EKO SATRIO

FSPM 2010 2

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**MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA**

2010

**EFFECT OF LOGGING OPERATIONS ON SOIL CARBON STORAGE OF
A TROPICAL PEAT SWAMP FOREST IN SARAWAK, MALAYSIA**



By

ANTON EKO SATRIO

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

April 2010



UPM

DEDICATION

Dedicated to those who always love, encourage and inspire me, for my parents, Agus Tri Anggono and Titis Sarwendah, my beloved wife Novita Dewi Ratnaningtyas, my beloved siblings, Nora Dwi Madona and Candra Tri Anggara.

It is also dedicated to those who have shared their times, worthy discussions and ideas during my study.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirement for the degree of Master of Science

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ANTON EKO SATRIO

April, 2010

Chairman : Seca Gandaseca, PhD

Faculty : Faculty of Agriculture and Food Sciences

There is little published data on the effect of logging operation on soil carbon storage of peat swamp forests. Furthermore, there is still lack of study that compares the damage level caused by “kuda-kuda” (sledge) skidding system and excavator skidding system in peat swamp forests. Thus, it is important to investigate the severity of degradation of peat swamp forest caused by logging operation in terms of its function as carbon storage. There are four major components of the logging operation, but the special concern remains the skidding component because it mainly interacts with the ground while extracting the trees through its damaging impact on the soil. The study area is located in an area bound by Batang Lebaan and Batang Igan River, adjacent to Sibu town. This peat swamp forest is Alan Batu forest type which is generally found on a more stressful environment of the peat swamp. In this study, it was assumed that conditions of the study site before the introduction of skidding system were in their natural state, and the changes measured are mainly caused by the skidding system. Therefore, the first part of this study was to determine the soil carbon storage of a tropical peat swamp forest in

their natural state. Variables obtained such as bulk density, soil pH, SOM, total carbon, total nitrogen, and C/N ratio was evaluated against their typical standard range that reported on earlier published references. The correlation between aforementioned chemical properties, humic acid (HA), unstable carbon, and stable carbon was examined. This tropical peat swamp forest portrays its specific natural state such as rich in SOM but had extreme acidic environment, thereby inhibiting decomposition of organic matter. It also had large amounts of total carbon, low total nitrogen, and high C/N ratio. The soil carbon storage in this tropical peat swamp forest relates to unstable carbon. A high value of soil carbon storage ($\pm 61.49\%$ of unstable carbon) in this peat swamp forest soil suggests that this natural tropical peat swamp forest plays an important role as a sink rather than a source of carbon. The second part of the study was to determine whether rainfall affects soil carbon storage of a tropical peat swamp forest and to determine the correlations which exist between variables (pH, SOM, total carbon, total nitrogen, total phosphorus, C/N ratio, C/P ratio, HA, unstable carbon, and stable carbon) that cause changes in soil carbon storage. The aforementioned variables of paired plots under two different rainfall gradients were compared and their correlations were examined. Stable carbon positively correlated with unstable carbon under higher rainfall. However, stable carbon had no association with unstable carbon under lower rainfall. The percentage of stable carbon of unstable carbon was 42.93% under lower rainfall, while that of higher rainfall was 62.69% suggesting that this natural tropical peat swamp forest plays an important role as a sink rather than a source of carbon under higher rainfall but inversely under lower rainfall. The third part of the study was to determine

whether skidding operations affects soil carbon storage of a tropical peat swamp forest. Bulk density and variables such as soil pH, SOM, total carbon, total nitrogen, total phosphorus, C/N ratio, C/P ratio, HA, unstable carbon, and stable carbon of independent plots under the two systems, “kuda-kuda” (sledge) and excavator skidding systems were compared and the correlations between variables were examined. It showed that the use of skidding systems on tropical peat swamp forest alters their carbon storage particularly unstable carbon by altering their decomposition rates. The fourth part of the study was to determine whether logging operation affect soil carbon storage of a tropical peat swamp forest. Variables such as soil pH, SOM, total carbon, total nitrogen, total phosphorus, C/N ratio, C/P ratio, HA, unstable carbon, and stable carbon under the two treatments (before and after logging) were compared and the correlations between these variables were examined. Result indicates that after the peat swamp forest is logged, humification maintained but the process slows and poor, hence unstable carbon decomposes faster instead of being preserved as stable carbon. Logging operations in this peat swamp forest does not alter their amount of soil carbon storage (stable carbon) due to the carbon in humic acid is quite stable within one year.

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

**PENGARUH OPERASI PEMBALAKAN TERHADAP PENYIMPANAN
KARBON TANAH HUTAN PAYA GAMBUT TROPIKA DI SARAWAK,
MALAYSIA**

Oleh

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Terdapat sedikit data yang diterbitkan mengenai pengaruh operasi pembalakan ke atas simpanan karbon tanah di hutan paya gambut. Selain itu, kajian mengenai perbezaan kesan kerosakan yang disebabkan oleh sistem pengheretan “kuda-kuda” dan *excavator* masih sedikit. Oleh yang demikian, kajian mengenai tahap kerosakan kritikal operasi pembalakan hutan paya gambut ke atas fungsinya dalam menyimpan karbon adalah sangat penting. Terdapat empat komponen utama dalam operasi pembalakan, walau bagaimanapun penekanan khusus diberikan ke atas komponen pengheretan kerana aktiviti tersebut mempunyai kesan kerosakan yang paling rapat dengan tanah ketika pokok dikeluarkan daripada hutan. Kawasan kajian terletak diantara Sungai Batang Lebaan dan Batang Igan berhampiran Bandar Sibu. Hutan paya gambut ini adalah daripada jenis hutan Alan Batu yang biasanya boleh dijumpai di kawasan paya gambut yang tertekan. Dalam penyelidikan ini, kawasan kajian diandaikan berada dalam keadaan yang semulajadi sebelum sistem pengheretan diperkenalkan,

dan perubahan yang berlaku adalah disebabkan oleh sistem pengheretan sahaja. Oleh itu, bahagian pertama kajian ini adalah untuk menentukan simpanan karbon tanah bagi hutan paya gambut tropika pada keadaan semulajadi. Pembolehubah yang diperolehi seperti ketumpatan pukal, pH tanah, bahan organik tanah, jumlah karbon, jumlah nitrogen, dan nisbah C/N dinilai terhadap julat piawai tipikal berdasarkan rujukan yang telah diterbitkan. Korelasi antara sifat-sifat kimia tersebut, asid humik, karbon tidak stabil, dan karbon stabil dikaji. Pada keadaan semulajadi yang tertentu, hutan paya gambut tropika kaya dengan bahan organik tanah tetapi mempunyai persekitaran yang sangat berasid yang menghalang penguraian bahan organik. Hutan paya gambut tropika juga mempunyai jumlah karbon yang tinggi, jumlah nitrogen yang rendah, dan nisbah C/N yang tinggi. Simpanan karbon tanah di dalam hutan paya gambut tropika ini terhasil daripada karbon yang tidak stabil. Nilai yang tinggi dari simpanan karbon tanah ($\pm 61.49\%$ daripada karbon tidak stabil) dalam tanah hutan paya gambut menunjukkan bahawa hutan paya gambut tropika semulajadi memainkan peranan yang penting sebagai penyimpan berbanding sebagai sumber karbon. Bahagian kedua kajian ini adalah untuk menentukan sama ada taburan hujan mempengaruhi simpanan karbon tanah di hutan paya gambut tropika dan untuk menentukan hubungkait yang wujud antara pembolehubah (pH, bahan organik tanah, jumlah karbon, jumlah nitrogen, jumlah fosforus, nisbah C/N, nisbah C/P, asid humik, karbon tidak stabil, dan karbon stabil) yang mempengaruhi perubahan simpanan karbon tanah. Pembolehubah tersebut dibandingkan dan dikaji hubungkaitnya daripada plot berpasangan pada dua cerun hujan yang berbeza. Hubungkait positif wujud

antara karbon stabil dan karbon tidak stabil pada kadar hujan yang lebih tinggi. Walau bagaimanapun, karbon stabil tidak mempunyai perkaitan dengan karbon tidak stabil pada kadar hujan yang lebih rendah. Peratusan karbon stabil daripada karbon tidak stabil adalah 42.93% pada kadar hujan yang lebih rendah, manakala pada kadar hujan yang lebih tinggi adalah 62.69% menunjukkan bahawa hutan paya gambut tropika semulajadi ini memainkan peranan yang penting sebagai penyimpan berbanding sebagai sumber karbon pada kadar hujan yang lebih tinggi tetapi kesan sebaliknya berlaku pada kadar hujan yang lebih rendah. Bahagian ketiga kajian ini adalah untuk menentukan sama ada operasi pengheretan mempengaruhi simpanan karbon tanah di hutan paya gambut tropika. Ketumpatan pukal dan pembolehubah seperti pH tanah, bahan organik tanah, jumlah karbon, jumlah nitrogen, jumlah fosforus, nisbah C/N, nisbah C/P, asid humik, karbon tidak stabil, dan karbon stabil daripada plot independen pada dua sistem (sistem pengheretan “kuda-kuda” dan *excavator*) dibandingkan dan korelasi antara pembolehubah dikaji. Keputusan menunjukkan bahawa penggunaan sistem pengheretan pada hutan paya gambut tropika telah mengubah simpanan karbon terutamanya karbon tidak stabil dengan perubahan kadar penguraian bahan organik. Bahagian keempat kajian ini adalah untuk menentukan sama ada operasi pembalakan mempengaruhi simpanan karbon tanah di hutan paya gambut tropika. Pembolehubah seperti pH tanah, bahan organik tanah, jumlah karbon, jumlah nitrogen, jumlah fosforus, nisbah C/N, nisbah C/P, asid humik, karbon tidak stabil, dan karbon stabil daripada dua rawatan (sebelum dan selepas pembalakan) dibandingkan dan korelasi antara pembolehubah tersebut dikaji. Keputusan menunjukkan bahawa selepas

pembalakan hutan paya gambut, proses humifikasi tetap berlaku walaupun secara lambat dan lemah, yang seterusnya penguraian karbon tidak stabil menjadi lebih cepat daripada dikekalkan menjadi karbon stabil. Operasi-operasi pembalakan di hutan paya gambut ini tidak mengubah kadar penyimpanan karbon tanah (karbon stabil) kerana karbon dalam asid humik adalah cukup stabil dalam jangka masa satu tahun.



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I certify that a Thesis Examination Committee has met on 6 April 2010 to conduct the final examination of Anton Eko Satrio on his thesis entitled “Effect of Logging Operations on Soil Carbon Storage of a Tropical Peat Swamp Forest in Sarawak, Malaysia” 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 Master of Science.

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DECLARATION

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



LIST OF TABLES

Table		Page
2.1	Estimates of peatland areas of tropical region	9
2.2	Estimates of the amount of carbon stored in tropical peatlands	12
2.3	Land use types of tropical peat swamp forest in Sarawak	13
2.4	Some selected peat soil properties	16
4.1	Soil chemical and physical properties of tropical peat swamp forest	49
4.2	Carbon storage in tropical peat swamp forest	51
4.3	Correlation between unstable C, stable C, and some selected chemical properties of a tropical peat swamp forest	52
4.4	Comparison of selected chemical characteristics of humic acid obtained with previous studies	54
5.1	Selected soil chemical properties under different gradient rainfall	59
5.2	Carbon storage in tropical peat swamp forest	61
5.3	Correlation between unstable C, stable C, and some selected chemical properties of a tropical peat swamp forest	63
5.4	Comparison of selected chemical characteristics of humic acid obtained with previous studies	64
6.1	Selected soil physical and chemical properties of a tropical peat swamp forest under different skidding systems	71
6.2	Carbon storage of a tropical peat swamp forest under different skidding systems	72
6.3	Correlation between unstable C, stable C and some selected chemical properties of peat swamp forest under different skidding systems	73
6.4	Comparison of selected chemical characteristics of humic acid	

	obtained with previous studies	75
7.1	Selected soil physical and chemical properties of a tropical peat swamp forest before and after logging operation	79
7.2	Carbon storage of a tropical peat swamp forest before and after logging operation	81
7.3	Correlation between unstable C, stable C and some selected chemical properties of peat swamp forest before and after logging operation	82
7.4	Comparison of selected chemical characteristics of humic acid obtained with previous studies	85



LIST OF FIGURES

Figure		Page
2.1	“Kuda-kuda” (sledge) skidding system	27
2.2	Excavator skids the logs in peat swamp forest	31
3.1	Location of the study area in Sibul	35
3.2	Monthly rainfall in 2008	36
3.3	Combination of rail transportation and excavator crawler	37
3.4	Excavator skidding system	39
3.5	The experimental plot (20 m x 50 m)	40
5.1	Daily rainfall fluctuation for January and March 2008	58

LIST OF ABBREVIATIONS

$(\text{NH}_4)_6 \text{Mo}_7\text{O}_{24}$	Ammonium molybdate
ASEAN	Association of Southeast Asian Nations
C	Carbon
cm	centimeter
CO_2	Carbon dioxide
COOH	Carboxyl group
FAO	Food and Agriculture Organization
g	gram
G	G-force
Gt	Gigatone
H^+	Hydrogen ion
H_2SO_4	Sulphuric acid
ha	hectare
HA	Humic Acid
HCl	Hydrochloric acid
HNO_3	Nitric acid
IUCN	International Union for the Conservation of Nature and Natural Resources
kg	kilogram
km	kilometer
$\text{KSbOC}_4\text{H}_4\text{O}_6$	Potassium antimonyl tartarate
m	meter
M	Molar

Mg	Mega gram
mL	milliliter
mm	millimeter
N	Nitrogen
NaHCO ₃	Sodium hydrogen carbonat
NaOH	Sodium hydroxide
NH ₄ ⁺	Ammonium ion
nm	nanometer
NO ₃ ⁻	Nitrate
°C	degree Celsius
OH	Hydroxyl group
P	Phosphorus
ppm	part per million
rpm	revolutions per minute
SAS	Statistical analysis system
SOM	Soil organic matter
β	beta

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGEMENTS	x
APPROVAL	xii
DECLARATION	xiv
LIST OF TABLES	xvii
LIST OF FIGURES	xix
LIST OF ABBREVIATIONS	xx
CHAPTER	
1 INTRODUCTION	1
1.1 Background	1
1.2 Objectives	6
2 LITERATURE REVIEW	7
2.1 Peat Swamp Forest	7
2.1.1 Definition	7
2.1.2 Distribution, Carbon Storage and Use	8
2.1.3 Peat Soil Properties	13
2.1.4 Soil Carbon Storage and Peat Swamp Forest Roles in Mitigating Global Warming	19
2.1.5 Influence of Climate and Water Level on Soil Carbon Storage of Tropical Peatland	22
2.2 Logging Operations	25
2.2.1 Definition	25
2.2.2 Skidding System on Peat Swamp Forest	26
2.2.2.1 "Kuda-kuda" (sledge) Skidding System	26
2.2.2.2 Excavator Skidding System	29
2.3 Stable Fraction of Carbon (Humic Acids)	31
2.4 Elemental and Functional Groups Analysis of Humic Acids	33
3 MATERIALS AND METHODS	35
3.1 Description of Study Area	35
3.2 Harvesting System Used at the Study Site	37
3.3 Soil Sampling	40
3.4 Soil Analysis	41
3.4.1 Bulk Density	41
3.4.2 Soil Acidity (pH)	41
3.4.3 Soil Organic Matter and Organic Carbon	42
3.4.4 Total Nitrogen	42
3.4.5 Total Phosphorus	43
3.5 Humic Acid Isolation	44

3.6	Humic Acid Characterization	45
3.6.1	Total Carbon and Ash Content Determination	45
3.6.2	Functional Groups and Total Acidity Determination	45
3.6.3	E ₄ /E ₆ Determination	46
4	INFLUENCE OF CHEMICAL PROPERTIES ON SOIL CARBON STORAGE OF A TROPICAL PEAT SWAMP FOREST	47
4.1	Introduction	47
4.2	Materials and Methods	48
4.3	Results and Discussion	49
4.4	Conclusions	54
5	EFFECT OF PRECIPITATION FLUCTUATION ON SOIL CARBON STORAGE OF A TROPICAL PEAT SWAMP FOREST	55
5.1	Introduction	55
5.2	Materials and Methods	57
5.3	Results and Discussion	57
5.4	Conclusions	64
6	EFFECT OF SKIDDING OPERATIONS ON SOIL CARBON STORAGE OF A TROPICAL PEAT SWAMP FOREST	66
6.1	Introduction	66
6.2	Materials and Methods	67
6.3	Results and Discussion	68
6.4	Conclusions	75
7	EFFECT OF LOGGING OPERATION ON SOIL CARBON STORAGE OF A TROPICAL PEAT SWAMP FOREST	77
7.1	Introduction	77
7.2	Materials and Methods	78
7.3	Results and Discussion	78
7.4	Conclusions	85
8	GENERAL CONCLUSION	87
	REFERENCES	89
	APPENDICES	97
	BIODATA OF STUDENT	100
	LIST OF PUBLICATIONS	101

CHAPTER 1

INTRODUCTION

1.1 Background

Peat swamp forests worldwide play a vital role in maintaining carbon balance and maintaining ideal global temperature as well as storing substantial amount of carbon. Although it covers only about 3.3% of the world's land area (Hadi *et al.*, 2001), it has been estimated that peatland can store 15 to 25% of global terrestrial carbon and nitrogen (Batjes, 1996). In Sarawak, however, this ecologically vital forest is under various threats and its total area has been steadily shrinking. About 98.53% of the peat swamp forests in Sarawak are actually disturbed (Wong, 2004; Sawal, 2004). These peat swamp forests also had been logged on a commercial scale since it is among the main sources of timber (IUCN, 1991). As subject to logging and timber extraction, these peat swamp forests in Sarawak are prone to devastated by excessive and destructive timber extraction methods (Truong, 2004).

Logging operation involves log transportation or the movement of trees, logs, or segments of logs from one point to another (Conway, 1982). In other words, logging operation objectives are to prepare the trees for transportation and to transport them to the proper conversion facility with proper method and transportation facility. Environmental destruction should be the other

concern during its processes especially on sensitive forest site with peat soil (Nugent *et al.*, 2003).

There are four major components of the logging operation, *viz.* felling, skidding, loading, and log transportation (Conway, 1982). Felling is the first step in preparing trees for the market and the objectives are to maximize the value of the end use and minimizing cost of the subsequent harvest operations (Conway, 1982). Felling may contribute to peat swamp soil degradation, but skidding remains to be more significant, because it is the activity that interacts most with the ground while extracting the trees from the felling site to the landing site through the skid trail inside the forest. Both log transportation and loading do not have direct significant interaction with the ground inside the forest.

Logging operation in this peat swamp forest studied is associated with land clearing activities and conversion of this natural peatland into oil palm plantation. According to Page *et al.* (2007), conversion of natural peatlands either by converted to another land use, deforestation or drainage which is likely reduces peatland areas is contribute to inaccurate data and bias estimation such as in location and extent, depth or thickness as well as carbon stored in tropical peatlands.

Meanwhile, there is little published data on the effect of logging operation on soil carbon storage of peat swamp forests. Furthermore, there is still lack of study that compares the damage level caused by “kuda-kuda” (sledge)

skidding system and excavator skidding system in peat swamp forests. Hence, it is important to investigate the severity of degradation of peat swamp forest caused by logging operation in terms of its function as carbon storage.

It is necessary to describe skidding operation prior to formulation of the operational questions. The following descriptions only comprise brief explanation that is needed to describe some of the processes involved. The process starts when skidders leave the landing to the stump or felling site through the skid trail that was built before felling activities. After skidders arrived at the felling site or leaves a recognizable skid trail, the process continues with bunching or loading activity. It involves all activities necessary to accumulate the logs as well as attaching the logs to the skidder(s) with chokers, chain, or grapples. When the logs are ready, skidding begins. It begins when the skidders turn back to a recognizable skid trail and skids (extracts) the logs along the ground and ends when they arrive at the landing site. Log landing includes chasing or unhooking and decking.

Primary skid trails must be laid out following environmental guidelines to minimize soil disturbance and erosion. Furthermore, the skid trails should be kept as straight as possible and should follow a favorable grade to the landing (Conway, 1982). However, proper equipment is also an important consideration, especially on sensitive forest sites such as on peat soils (Nugent *et al.*, 2003). As previously mentioned, the focus of this study is to compare the usage of extraction method or equipment between “kuda-kuda”

(sledge) and excavator skidding systems in terms of its impact on peat swamp forest soil. Generally, processes involved are almost the same when it is assumed that the skidding distance, volume of logs per area, soil characteristics and slope are the same. The differences are due to dominant power involved. "Kuda-kuda" (sledge) system involves human power or labour intensive (Sawal, 2004) while excavator system is machine powered. This may cause different penetration to the soil during extraction while swampy condition has its special threshold to receive such different skidding systems. The other differences are load size capacity per trip, roundtrip time, and roundtrip intensity.

Some operational questions which cover the main issues and approaches planned to addressing the answers are presented below:

1. Does logging operation within skidding component whether the use of "kuda-kuda" (sledge) or excavator skidding systems alter the soil carbon storage of peat swamp forest?

Approach: The soil carbon storage conditions of peat swamp forest before and after these skidding systems applied were investigated within proper and/or possible research design, methods and analyses.

2. How much does logging operation within skidding component whether the use of "kuda-kuda" (sledge) or excavator skidding systems contribute to the soil carbon storage changes of peat swamp forest?

Approach: The aforementioned approach in point number (1) also directed to answer this point. Therefore, the information obtained from

point number (1) also comprises the quantity of soil carbon storage itself under both skidding systems.

3. If the logging operation within skidding component whether the use of “kuda-kuda” (sledge) or excavator skidding systems both alter the soil carbon storage of peat swamps forest, which one has the great effect or disturbances?

Approach: Paired or dependent test could give the accurate results to compare the effect of both skidding systems and detect their disturbances level. Based on preliminary observations, however, it seems that dependent test only possible approach to compare disturbances level between before and after excavator skidding system applied, while independent test could be used to compare disturbances level between “kuda-kuda” (sledge) and excavator skidding systems.

However, prior to the commencement of the study, careful selection of the study site at the peat swamp forest concession area was done by ensuring the representatively of the experimental site as undisturbed (natural state conditions) peat swamp forest as well as their soil carbon storage to avoid misleading conclusion. This is to ensure that changes and or differences measured are clearly caused by skidding systems.

4. If the logging operation within skidding component whether the use of “kuda-kuda” (sledge) or excavator skidding systems both do not alter the soil carbon storage of peat swamp forest, are there any other factors that

significantly influence to the soil carbon storage changes of peat swamp forest?

Approach: The amount of rainfall varies markedly daily and annually in tropical region while temperature can be constant (Jauhiainen *et al.*, 2005). Therefore, rainfall may affect the soil carbon storage of peat swamp forest. Rainfall data during soil sampling (before skidding systems applied) was collected as a set of secondary data. It was found different rainfall fluctuation during soil sampling on January and soil sampling on March. Thus, soil carbon storage under those rainfalls was compared.

1.2 Objectives

The objectives of the study were as follows:

1. To determine and compare the quantity of soil carbon storage (stable fraction of carbon) of a tropical peat swamp forest before and after logging operation (excavator skidding system).
2. To determine and compare the quantity of soil carbon storage (stable fraction of carbon) of a tropical peat swamp forest under “kuda-kuda” (sledge) and excavator skidding systems.
3. To determine the association between soil carbon storage (stable fraction of carbon) with pH, soil organic matter, total carbon, total nitrogen, total phosphorus, C/N ratio, C/P ratio, and unstable carbon of a tropical peat swamp forest.
4. To determine whether rainfall affects the soil carbon storage (stable fraction of carbon) of a tropical peat swamp forest.

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Anton Eko Satrio was born in Ngawi, East Java, Indonesia in 31 October 1981. He received his primary education from Sekolah Dasar Negeri 1 Jogorogo, Ngawi before continuing his education at Sekolah Menengah Pertama Negeri 2 Ngawi (junior high school) from 1994-1997 and Sekolah Menengah Umum Negeri 2 Ngawi (senior high school) from 1997-2000. He received B.Sc. degree from Faculty of Forestry, Bogor Agricultural University Indonesia in 2005. In December 2007, he enrolled as a full time master student at Universiti Putra Malaysia. So far, his research work has been published in 4 international journals, 1 proceeding at the international conference and 1 proceeding at the international symposium. Currently he is working at The Ministry of Forestry Republic of Indonesia.

LIST OF PUBLICATIONS

1. Anton Eko Satrio, Seca Gandaseca, Osumanu Haruna Ahmed, and Nik Muhamad Abdul Majid, 2009. Influence of chemical properties on soil carbon storage of a tropical peat swamp forest. *American Journal of Applied Sciences* 6: 1970-1973.
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