UNIVERSITI PUTRA MALAYSIA

FOREST RECOVERY AFTER SUPERVISED AND CONVENTIONAL LOGGING IN ULU MUDA FOREST RESERVE, KEDAH, MALAYSIA

SEYED MOUSA SADEGHI

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By

SEYED MOUSA SADEGHI

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

May 2016

DEDICATION

THIS THESIS IS ESPECIALLY DEDICATED TO:
MY BELOVED FAMILY
FARIBA, BAHARSADAT, SEYEDEH NEGAR AND SEYED MOHAMMADREZA
MY MOTHER AND MY LATE FATHER

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the Degree of Doctor of Philosophy

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Chairperson : Prof. Datin Faridah Hanum Ibrahim, PhD
Faculty : Forestry

The hill dipterocarp forests (HDF) in the Ulu Muda Forest Reserve (UMFR) were logged under supervised logging (SLo) (Compartment 25A) and conventional logging (CL) (Compartment 28A) methods. Knowledge on forest recovery in terms of tree species composition, forest structure, biomass and soil of HDF after 14 and 16 years of logging is of great importance for the management of forests. A systematic sampling layout was used to assess forest recovery after supervised and conventional logging on species composition, forest structure biomass and soil physico-chemical properties. In 80 plots (50 m × 20 m) all stems with diameter at breast height (DBH) ≥ 1 cm were enumerated, measured and identified. In terms of tree species composition, forest structure, biomass and soil, data were compared between Compartments (SLo & CL) or with Pre-Felling (Pre-F) data in order to find the forest recovery after SLo and CL. The soil samples in 27 sub-plots were collected. The chemical and physical analyses of soil were performed. The soil fertility index (SFI) and soil evaluation factors (SEF) were calculated to compare the differences of soil recovery between SLo and CL sites. In term of species composition 501 species belonging to 208 genera and 71 families were recorded. The tree species composition of the study site contributed to 17.7%, 40.6% and 71.0% of total tree species, genera and families found in Peninsular Malaysia; of these 79 are endemic species including eight rare species and one very rare species. Five new records for Kedah; *Diospyros apiculata*, *Diospyros argentea*, *Macaranga recurvata*, *Macaranga constricta* and *Cryptocarya bracteolata* were found in the study site. Euphorbiaceae was the most diverse family, followed by Lauraceae, Annonaceae, Rubiaceae and Meliaceae. In term of species importance value index (IVI) *Shorea macroptera* (26.0) and *Ochanostachys amentacea* (26.7) were the two most important species in the SLo and CL sites, respectively. In term of family importance value (FIV) Euphorbiaceae was the most important family in the SLo (70.2) and CL (78.2) sites. The forests after SLo and CL are still rich in biodiversity this is shown by Margalef index of SLo and CL sites were 49.58 and 33.38, respectively. Shannon-Weiner, Simpson and Fisher indices for SLo and CL sites were 5.44 and 4.89, 151.4 and 84.5, 119.7 and 70.36, respectively. Smith and Wilson evenness values of SLo and CL sites were 0.46 and 0.38, respectively. The difference between diversity indices of SLo and CL sites were significant at 5% level. Sorensen and Jaccard similarity indices between

SLo and CL sites were 0.60 and 0.43, respectively. Considering the recovery, in term of species composition the SLo site recovered more than CL site which was 63.1%. In term of forest structure for trees with DBH > 5 cm, the mean values of tree density of SLo (636.6 stem ha^{-1}) and CL (620.6 stem ha^{-1}) sites were significantly higher than Pre-Felling (Pre-F) data (448.2 stem ha^{-1}) (Sig. = 0.000 in both sites). Distribution of tree density based on tree groups (DBH ≥ 5 cm) showed that small pole, big pole, and small tree groups recovered up to or more than Pre-F data. The average basal area of trees with DBH > 15 cm, from Pre-Felling data (24.7 m^2 ha^{-1}) was higher than the values of inventory data in the SLo (21.1 m^2 ha^{-1}) and CL (17.2 m^2 ha^{-1}) sites (Sig. = 0.03 and Sig. = 0.00 for SLo and CL sites, respectively). With respect to tree volume for trees with DBH > 15 cm, the inventory data of SLo (148.0 m^3 ha^{-1}) and CL (123.0 m^3 ha^{-1}) sites were significantly lower than Pre-Felling data (205.7 m^3 ha^{-1}) (Sig. = 0.001 and 0.000 for SLo and CL sites, respectively). Trees with DBH 15-45 cm recovered in term of tree density, basal area and volume when compared with Pre-Felling data. The mean values of total biomass and total carbon for tree (DBH ≥ 1cm) in the SLo site were 326.7 ton ha^{-1} and 163.4 ton ha^{-1}, respectively but were non-significantly higher than those values in the CL site (275.2 ton ha^{-1} and 137.6 ton ha^{-1}, respectively) (Sig. = 0.3). Forest recovery of tree species diversity, basal area, tree volume and total biomass in terms of percentage in the SLo site was higher than the values of CL site by 14.3%, 22.7%, 20.3% and 21.8%, respectively. However, in terms of tree density, basal area and volume for trees with DBH > 15 cm, a big loss value (Pre-F value minus value from inventory data) was found when compared to the overall inventory data with Pre-Felling data. The loss value for tree density, basal area, and volume of SLo site were 48.7%, 14.6%, 28.1% and that of CL site were 52.5%, 30.4% and 40.2%, respectively. The forest in both sites has five strata. The soil evaluation factor (SEF) of SLo site (9.2±4.1) was non-significantly (4.3%) smaller than that value of CL (9.6±3.6) site (Sig = 0.8). The soil fertility index (SFI) of CL site was non-significantly higher than SLo site (Sig. = 0.4). Results showed that logged forest recovered in terms of species composition, diversity and forest structure for trees with DBH 1-45 cm, but not for trees of DBH > 45 cm. In terms of biomass the logged forest to some extent recovered but 14 and 16 years after logging were not sufficient for forest to recover up to its fully capacity. For soil recovery, it needs more than 14 and 16 years after logging. The result showed that 3-ha and 5-ha sampling size in the both study sites were not enough to capture the plant diversity of study sites. Hence, further study was suggested to find the optimum plant diversity sampling size. In order to improve accuracy of biomass estimation in logged-over HDF it was recommended to do future study for generating biomass equation. Results of this study could be useful for both decision makers and foresters to improve tropical rainforest management.

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

PEMULIHAN HUTAN SELEPAS PEMBALAKAN TERKAWAL DAN KONVENSIONAL DI HUTAN SIMPAN ULU MUDA, KEDAH, MALAYSIA

Oleh

SEYED MOUSA SADEGHI

Mei 2016

Pengerusi : Prof. Datin Dr. Faridah Hanum Ibrahim
Fakulti : Perhutanan

Hutan bukit dipterocarp (HDF) di Hutan Simpan Ulu Muda (UMFR) dibalak mengikut kaedah pembalakan terkawal (SLo) (Kompartmen 25A) dan pembalakan konvensional (CL) (Kompartmen 28A). Pengetahuan tentang pemulihan hutan dari segi komposisi spesies pokok, struktur hutan, biojisim dan tanah untuk HDF selepas 14 dan 16 tahun pembalakan adalah amat penting untuk pengurusan hutan. Pelan pensampelan bersistem digunakan untuk menilai pemulihan hutan selepas pembalakan secara terkawal dan konvensional dari aspek komposisi spesies, struktur hutan, biojisim dan kandungan fizik-kimia tanah. Dalam 80 plot (50m x 20m), semua dirian pokok dengan diameter (DBH) ≥ 1cm dikira, diukur dan dikenal pasti. Dari segi komposisi spesies, struktur hutan, biojisim dan tanah, data telah dibandingkan di antara kompartmen (SLo dan CL) atau dengan data sebelum tebangan (Pre-F) untuk mengukur pemulihan hutan selepas SLo dan CL. Sampel tanah dikumpul dari 27 sub-plot. Analisis kimia dan fizikal tanah telah dijalankan. Indeks kesuburan tanah (SFI) dan faktor penilaian tanah (SEF) diambil kira bagi membandingkan perbezaan pemulihan tanah antara lokasi SLo dan CL. Dari segi komposisi spesies, 501 spesies dari 208 genera dan 71 famili telah direkodkan. Komposisi spesies pokok di kawasan kajian menyumbang 17.7% dan 71.0% kepada jumlah keseluruhan spesies pokok, genera dan famili yang diketahui di Semenanjung Malaysia; 79 adalah spesies endemik termasuk lapan spesies yang jarang ditemui dan satu spesies yang sangat jarang ditemui. Lima rekod baru untuk Negeri Kedah telah ditemui di kawasan kajian; *Diospyros apiculata, argentea Diospyros, Macaranga recurvata, Macaranga constricta* dan *Cryptocarya bracteolata*. Euphorbiaceae merupakan famili yang paling pelbagai direkodkan diikuti oleh Lauraceae, Annonaceae, Rubiaceae dan Meliaceae. Dari segi nilai kepentingan spesies (IVI), *Shorea macroptera* (26.0) dan *Ochanostachys amentacea* (26.7) adalah dua spesies yang paling penting dalam kawasan SLo (70.2) dan CL (78.2). Nilai kepentingan famili (FIV) merekodkan Euphorbiaceae sebagai famili yang paling penting dalam kawasan SLo (70.2) dan CL (78.2). Keadaan hutan selepas SLo dan CL didapati masih kaya dengan biodiversiti seperti yang ditunjukkan oleh indeks Margalef untuk SLo dan CL masing-masing adalah 49.58 dan 33.38. Indeks Shannon-Weiner, Simpson dan Fisher untuk kawasan SLo dan CL masing-masing adalah 5.44 dan 4.89, 151.4 dan 84.5, 119.7 dan 70.36. Indeks keseragaman Smith dan Wilson untuk kawasan SLo dan CL masing-masing adalah 0.46 dan 0.38. Perbezaan antara indeks kepelbagaian bagi kawasan SLo dan CL adalah signifikan pada aras 5%. Indeks persamaan Sorensen dan Jaccard antara kawasan SLo dan CL masing-masing adalah 0.60 dan 0.43. Dengan mengambil kira pemulihan hutan, komposisi spesies di kawasan SLo lebih tinggi kadar pemulihan berbanding kawasan CL sebanyak 63.1%. Dari aspek struktur hutan untuk pokok dengan DBH > 5 cm, nilai min untuk kepadatan pokok di kawasan SLo (636.6 batang ha^{-1}) dan CL (620.6 batang ha^{-1}) ternyata lebih tinggi berbanding data Pre-F (448.2 batang ha^{-1}) (Sig. = 0.000 bagi kedua-dua kawasan). Taburan kepadatan pokok berdasarkan kumpulan pokok (DBH ≥ 5 cm) menunjukkan bahawa pemulihan pokok yang berdiameter kecil, besar dan kumpulan pokok kecil hampir menyamai atau melebihi dari data Pre-F. Purata luas pangkal pokok dengan DBH > 1.5 cm dari data Pre-F (24.7 m^2 ha^{-1}) lebih tinggi daripada nilai data inventori di kawasan SLo (21.1 m^2 ha^{-1}) dan CL (17.2 m^2 ha^{-1} (Sig. = 0.03 dan Sig. = 0.00 untuk kawasan SLo dan CL). Merujuk kepada isipadu pokok bagi pokok-pokok yang mempunyai DBH > 1.5 cm, data inventori untuk kawasan SLo (148.0 m^3 ha^{-1}) dan CL (123.0 m^3 ha^{-1}) ternyata lebih rendah dari data Pre-F (205.7 m^3 ha^{-1}) (Sig. = 0.001 dan 0.000 untuk kawasan SLo and CL). Pokok-pokok dengan DBH 15-45 cm telah pulih dari segi kepadatan pokok, luas pangkal dan isipadu apabila dibandingkan dengan data Pre-F. Nilai min bagi jumlah biojisim dan karbon untuk pokok (DBH ≥ 1cm) di kawasan SLo masing-masing ialah 326.7 tan ha^{-1} dan 163.4 tan ha^{-1} tetapi ternyata tidak tinggi jika dibandingkan dengan nilai di kawasan CL (275.2 tan ha^{-1} dan 137.6 tan ha^{-1}) (Sig. = 0.3). Pemulihan hutan dari aspek kepelbagaian spesies pokok, luas pangkal, isipadu pokok dan jumlah biojisim dalam peratusan di kawasan SLo lebih tinggi dibandingkan dengan nilai di kawasan CL dengan nilai masing-masing ialah 14.3%, 22.7%, 20.3% dan 21.8%. Walaubagaimanapun, dari segi kepadatan pokok, luas pangkal dan isipadu pokok dengan DBH > 15 cm, nilai kehilangan (Nilai Pre-F tolak Nilai data inventori) diperolehi dengan membandingkan keseluruhan data inventori dengan data Pre-F. Nilai kehilangan untuk kepadatan pokok, luas pangkal dan isipadu di kawasan SLo masing-masing adalah 48.7%, 14.6%, 28.1% manakala di kawasan CL masing-masing adalah 52.5%, 30.4% dan 40.2%. Hutan di kedua-dua kawasan mempunyai lima strata. Faktor penilaian tanah (SEF) untuk kawasan SLo (9.2±4.1) (4.3%) lebih kecil berbanding dari nilai kawasan CL (9.6±3.6) (Sig = 0.8). Indeks kesuburan tanah (SFI) untuk kawasan CL ternyata lebih rendah berbanding kawasan SLo (Sig. = 0.4). Keputusan menunjukkan bahawa pemulihan hutan yang telah dibalak dari segi komposisi spesies, kepelbagaian dan struktur hutan adalah untuk pokok-pokok dengan DBH 1-45 cm tetapi bukan untuk pokok yang mempunyai DBH > 45 cm. Dari segi biojisim, hutan yang dibalak akan pulih mengikut jangka masa tertentu namun, 14 dan 16 tahun selepas pembalakan tidak cukup untuk pemulihan kapasiti hutan sepenuhnya kepada yang asal. Bagi pemulihan tanah, ia memerlukan lebih dari 14 dan 16 tahun selepas pembalakan. Keputusan menunjukkan bahawa saiz pensampelan 3-ha dan 5-ha di kedua-dua kawasan kajian tidak mencukupi untuk merekodkan keseluruhan kepelbagian tumbuhan kawasan kajian. Oleh itu, kajian lanjut disarankan untuk mendapatkan saiz pensampelan biodiversiti yang optimum. Bagi memperbaiki ketepatan anggaran biojisim dalam HDF yang telah dibalak, adalah dicadangkan supaya kajian lanjut dilaksanakan untuk menjana persamaan biojisim. Keputusan dari kajian ini boleh digunakan oleh pihak pembuat keputusan dan pengurusan hutan untuk menambahbaik pengurusan hutan hujan tropika.

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I certify that a Thesis Examination Committee has met on 11 May 2016 to conduct the final examination of Seyed Mousa Sadeghi on his thesis entitled "Forest Recovery after Supervised and Conventional Logging in Ulu Muda Forest Reserve, Kedah, 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 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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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AGB	Above ground biomass
Al	Aluminum
ALo	After logging
AP	Available Phosphorous
BCI	Barro Colorado Islands
BL	Before logging
BS	Base Saturation
CEC	Cation exchangeable capacity
CL	Conventional logging
Com	Compartment
DBH	Diameter at breast height
Dip	Dipterocarp
ECEC	Effective cation exchangeable capacity
FAO	Food and Agricultural Organization
FDPM	Forestry Department Peninsular Malaysia
FQA	Floristic Quality Assessment
ha	Hectare
HDF	Hill dipterocarp forest
ITTO	International tropical timber organization
IUCN	International Union for Conservation of Nature and Natural Resources
LDF	Lowland dipterocarp forest
mg/kg	Milligram per kilogram
N-dip	Non-dipterocarp
P	Phosphorous
Pre-F	Pre-Felling
RIL	Reduced impact logging
SA	Species abundance
SEF	Soil evaluation factor
SFI	Soil fertility index
SL	Sampling line
SLo	Supervised logging
SMS	Selective management system
SOM	Soil organic matter
SS	Secondary succession
STDEV	Standard deviation
T-C	Total carbon
TD	Tree density
TMCF	Tropical montane cloud forest
TRF	Tropical rainforest
UMFR	Ulu Muda Forest Reserve
W	Watershed

CHAPTER 1

INTRODUCTION

1.1 General Background

The total forest area worldwide is above 4.033 billion ha, which is averagely equal to 0.6 ha per person (FAO, 2010). Tropical forests are around one third of the entire forest surface of the world (Thomas & Baltzer, 2002). These forests (located in the south America, Southeast Asia, South Asia and Africa) account 23.2% of the total production of round and sawn wood of the world (FAO, 2011). Although tropical forests cover 7% of the planet area, they contain over half of the biological diversity of the earth (Thomas & Baltzer, 2002). There are 24 biodiversity hotspots in the world. The majority of biodiversity hotspots are located in tropical ecosystem (Myers et al., 2000). The future of tropical forests will be affected by anthropogenic drivers such as change of land use, timber harvesting, animal hunting, atmospheric change and flux of climate (Wright, 2010).

The total natural forest area of Malaysia was around 18.4 million ha, which covers about 56% of the total surface of country (FAO, 2010). Small parts of tropical rainforests of Malaysia are richer in terms of tree species than similar areas in African and American tropical rainforests (Whitmore & Burnham, 1984). Malaysia is one of the 12 megadiverse countries. Among 15,000 species of flowering plants in Malaysia, 2,830 are tree species in 100 families and 532 genera (Ng et al., 1990; Bidin & Latiff, 1995). Four main groups of forests including climate, edaphic, biotic climax formation and unstable forest were recognized in Malaysian tropical rainforests (Symington et al., 2004). Those main groups were divided into 16 types of forests (Symington et al., 2004) including the hill dipterocarp forest (HDF) which is economically important and provides many ecosystem services to the community (Latiff & Faridah-Hanum, 2005).

Species composition, structure and soil of tropical rainforests were affected by logging operations (Pinard et al., 2000; Yamada et al., 2013). Saiful (2002) reported that conventional logging operations affected species composition, stand structure and soil of HDF at Ulu Muda Forest Reserve (UMFR), in the Kedah, Malaysia. To reduce the effects of logging on forest ecosystem, selective logging method was improved (Pinard et al., 1995). Forshed et al. (2006) showed that, supervised logging method with parallel pre-marked skid trails and directional cutting were helpful in reducing logging damages to residual stands compared with conventional methods in Sabah, Malaysia.

Due to the global consciousness of increasing deforestation and forest degradation many tropical countries including Malaysia (Latiff, 2011) and Indonesia (Sist et al., 1998a), prioritized to achieve International Tropical Timber Organizations (ITTO's) goals to manage forests under sustainable management approach. Malaysia has practiced the sustainable forest management to safeguard forest harvesting and protection go hand in hand (Latiff, 2011). Improvement towards sustainable forest management needs implementation of several controlling measures which are related to reducing damage to forest environment (Forshed et al., 2006). Supervised logging was "efficient" for sustainability of logging when compared with conventional logging because in this system the forest damage was less than conventional (Forshed et al., 2006).

Ulu Muda Forest Reserve (UMFR) includes both the lowland and hill dipterocarp forests located in the North-west of Peninsular Malaysia (Kedah State). The forest consists of an area of 162,000 ha including three main districts (Baling, Sik and Padang Terap) that have been considered as permanent forest reserve since 1932. The importance of UMFR is related to many ecosystem services, in addition to timber provision especially as watershed for the Muda and Pedu Lakes (Latiff & Faridah-Hanum, 2005). Parts of the Ulu Muda Forest Reserve could also be one of the main ecotourism destinations for Peninsular Malaysia (Mariana et al., 2008). Compartments 25A and 28A of UMFR were subjected to supervised logging and conventional logging operations in 2000 and 1998, respectively (Saiful, 2002). To reduce the impact of logging operations on the forest ecosystem, control and supervision of both logging planning and operations in the field in supervised logging (SLo) site must be supervised by "Supervisory Field Team" based on guidelines and schedules (Pinard et al., 1995; Sist et al., 1998a; Forshed et al., 2006). However, in the conventionally logged (CL) area, except the cutting limitation, the rest of logging activities were not supervised by "Supervisory Field Team".

The reaction of tropical rainforest towards both anthropogenic and natural disturbances is one of the most crucial aspects in ecological studies (Lugo & Brown, 1986; Grace, 2004; Chave et al., 2005). The protection of primary forest is significant for biodiversity conservation and climate change mitigation; the secondary forest must also be considered for the same crucial roles (Berry et al., 2010). Incorporating floristic composition, stand structure and soil quality of logged-over forest after logging is a crucial point in considering forest recovery procedures and planning of forest management policies in diverse disruption regimes (Gutiérrez & Huth, 2012; Kalaba et al., 2013). In addition, quantification of biomass and carbon storage of forest ecosystem could also give an indication in the improvement of the payment for ecosystem services (Baker et al., 2010).

1.2 Statement of Problem

Logging has increased the ecological problems including forest degradation and biodiversity loss (Pimm & Gittleman, 1992; Latiff, 2011), soil erosion (Akkharath, 2005) and depletion of biomass and carbon storage of forest (Wright, 2010). To achieve a sustainable forest management, fundamental information in terms of ecological variables including tree composition, stand structure and soil are necessary (Brooks, 1990).

As a management system, the Malayan Uniform System (MUS) has been practiced since 1948 to manage lowland dipterocarp forest, and in 1978 the selective management system (SMS) had been started in HDF in Peninsular Malaysia (Latiff, 2011). The selective management system (SMS) affected tree diversity and tree size classes (Latiff, 2011). Selective logging is the most popular method for timber harvesting in South-East Asia, and its impacts on forest composition, stand structure and soil of tropical rainforests are the main concern of most ecologists and foresters (Okuda et al., 2003).

Forest recovery after disturbances differed from site to site. Bonnell et al. (2011), reported that the time of forest recovery could be different based on wildlife species and plant species. It was expressed that more specific studies are required to demonstrate the effects of logging on forest recovery in terms of biodiversity. Some published data on forest recovery have covered plant species composition, structure and biomass. For instance, Feeley et al. (2007) showed that above-ground biomass increased 0.72% $year^{-1}$ at Pasoh Forest Reserve, Malaysia. Hjerpe et al. (2001) pointed out that *Macaranga harveyana*, was abundant in unburnt and burnt area in Samoa Island while Howlett & Davidson (2003) found that *Macaranga winkleri*, and *Callicarpa longifolia*, were the most abundant species in the tropical rainforest in Malaysia. Bonnell et al. (2011) pointed out that species diversity, basal area and stem density can be used to determine the forest recovery. Some of them are in line with soil recovery such as Amlin et al. (2014) who showed that soil nutrient components were low in tropical rainforest in Malaysia 30-years after logging. Ashton (1989) metioned that mixed dipterocarp forest on fertile soil was less diverse than mixed dipterocarp forest on poor soil although gaps were larger and more frequent among dipterocarps on more fertile soil in Sarawak. It was found that α-diversity was bigger where there were fewer and smaller gaps (Leigh et al., 2004). This was supported by Fedorov (1966) who explained the interaction of the following reasons for high diversity on poor soils of tropical rainforests: small size of population of tree species, low population density, biotic isolation between populations and between individuals, and other factors such as absence of seasonal rhythm, non-regular flowering, and consequent difficulty of cross-pollination created favorable condition for speciation in tropical rainforest. Later, Leigh et al. (2004) reported that disturbances and microhabitat specialization maintained tree diversity in north Mexico. It was mentioned that where trees grow readily, tree diversity is higher and precipitation and temperature were less seasonal. Leigh et al. (2004) found that high level of pest pressure on trees maintained higher tree diversity in sites where winter was absent. Tucker et al. (1998) noted that rate of forest recovery was influenced by history of land use management and soil fertility. The degree of soil disturbance and soil depth affected the rate of the recovery of the organic matter content, macro-porosity and bulk density (Rab, 2004). Deforestation decreased the amount of soil organic carbon and total nitrogen (Sahani & Behera, 2001). Monitoring of forest recovery after logging is a significant aspect in ecological studies for forest managers (Moran et al., 2000).

Sustainable forest management, which has been practiced in Malaysia, needs more fundamental knowledge. Further studies in terms of species composition, structural aspects and soil of hill dipterocarp forest are necessary to assess the effects of logging on the recovery of hill dipterocarp forest. If we do not have essential information about forest ecosystem, not only the time and the money can be wasted, but also the forest resources can be degraded. This study could provide useful information and insights about the tree species composition, stand structure, biomass, and soil changes after logging. Similarly, this part of knowledge can help decision makers and foresters to improve tropical rainforest management.

1.3 Objectives

The overall objective of this research was to assess forest recovery in hill dipterocarp forest after conventional and supervised logging in terms of tree species composition, forest structure, biomass, and soil physico-chemical properties. The specific objectives were:

1) To investigate the species composition, diversity and forest structure (density, basal area, and volume) of a logged-over hill dipterocarp forest after supervised and conventional logging
2) To estimate the biomass after supervised and conventional logging in a logged-over hill dipterocarp forest.
3) To compare effects of supervised and conventional logging on recovery of soil physico-chemical properties.

1.4 Thesis Organization

This thesis consists of five chapters. Chapter one introduces the topic and provides a general outline of the present study.

Chapter two represents a literature review on biodiversity, biomass, forest structure, soil and the effects of logging on forest ecosystem.

Chapter three represents the methodology used in this research.

Chapter four gives the results and discussions.

Chapter five as a concluding chapter synthesizes the results and summarizes them as the main findings of the research. The recommendations for future researches are also presented in this chapter.

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