TECHNICAL INFORMATION ON OPTIMUM HARVESTING REGIMES OF PEAT SWAMP FORESTS IN PENINSULAR MALAYSIA

Editors
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CONTENTS

EDITORS' NOTE

It is important to develop a specific management system for productive peat swamp forest based on this forest's physical and ecological characteristics. Among the significant aspects of forest management is optimum harvesting which is critical in achieving sustainable management of all forest types, including the peat swamp forest. This book is one of the publications of the ITTO-CITES Project, a FRIM activity. Although, the project's main activities are conducted under the Levy Funding Grant provided by the Ministry of Plantation Industries and Commodities, Malaysia, a portion of the study and the publication of this book were funded by the ITTO-CITES Project.

There are eight chapters in this technical handbook starting from Project background, followed by Development of cutting options, Impact of reduced impact logging, Determination of optimum harvesting, Financial evaluation, Productivity and time study of reduced impact logging, Hydrological response and ending with Development of a local volume table (LVT) for *Gonystylus bancanus* in Pekan Forest Reserve, Pahang. Outputs from this optimum harvesting project could be applied to other productive forest subtypes in the Pekan Forest Reserve itself. Moreover, they could be further extended to other productive peat swamp forests in Selangor and Sarawak. It hoped that information provided in this book will be another added important reference to improving the management and conservation of peat swamp forests in our country.

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Appreciation is extended to the Forestry Department of Pahang as counterpart of this project for providing assistance in plot establishment and security, data collection and report writing. The staff of the Natural Forest Programme, FRIM, also helped in data collection and analysis. The project was funded by the Levy Funding Grant under the Ministry of Plantation Industries and Commodities, Malaysia. The ITTO-CITES Project is gratefully acknowledged for funding the publication of this handbook.

ABBREVIATIONS & ACRONYMS

BCA	benefit-cost analysis
BN	Bintangor
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DANCED	Danish Cooperation for Environment and Development
DANIDA	Danish International Development Assistance
dbh	diameter at breast height
DM	Dipterocarps meranti
DNM	Dipterocarps non-meranti
FCS	forest checking station
FR	forest reserve
FRIM	Forest Research Institute Malaysia
GEF	Global Environment Facility
GWL	groundwater level
GYMMTF	Growth and Yield Model for Mixed Tropical Forest
GYMTPSF	Growth and Yield Model for Tropical Peat Swamp Forest
ha	hectare
hr	hour
IMP	Integrated Management Plan
IRR	internal rate of return
ITTO	International Tropical Timber Organization
JTR	Jalan Tarik Rimbaka
LVT	local volume table
m	meter
MAI	mean annual increment
MC&I	Malaysia Criteria & Indicators
MUS	Malayan Uniform System
NDHHW	Non-dipterocarps heavy hardwoods
NDLHW	Non-dipterocarps light hardwoods
NDMHW	Non-dipterocarps medium hardwoods
NDMICS	Non-dipterocarps misc.
NPV	net present value
PRF	permanent reserved forest
PSF	peat swamp forest
RIL	reduced impact logging
RTH	Rimbaka timber harvester
s	second
SEPPSF	South East Pahang Peat Swamp Forest
SFM	sustainable forest management
SMS	selective management system
UNDP	United Nations Development Program
yr	year

EXECUTIVE SUMMARY

Under the Forestry Act, the South East Pahang Peat Swamp Forest (SEPPSF) was gazetted as a permanent reserve forest (PRF) to be managed as a production forest. This allows logging activities to be carried out in the area but on a sustainable basis. The fact that there was still a lack of proper management system for the production peat swamp forest (PSF) prompted the Forest Research Institute Malaysia (FRIM) to undertake a specific study to develop an appropriate optimum harvesting system for the PSF. FRIM was allocated about RM790,000 by the Malaysian Government under the Levy Fund to determine the harvesting regimes for PSF in Peninsular Malaysia. In line with the objective of the UNDP/GEF funded project, the so-called "Harvesting regime study" has contributed to the Integrated Management Plan (IMP) and Forest Management Plan for Pekan Forest Reserve (FR), Pahang, particularly on the aspect of forest harvesting in the forest reserve.

In this study, Compartment 77 in Pekan FR was selected as the study site. The area is a productive rich forest of Ramin-Bintangor subtype located northeast of the forest reserve. The Ramin-Bintangor subtype represents about 20% (~ 10,000 ha) of the whole Pekan FR. An area of 100 ha in Compartment 77 was allocated for this study to present actual harvesting practices on the ground. The study area was divided into four blocks of 25 ha each for the testing of different cutting options developed by the project. Four sets of cutting regimes were developed based on primary and secondary data collected. The cutting regimes were prepared by taking into account species dominance in the area, volumes of timber to be taken out and numbers of residual trees and main species to be retained as future crops.

The cutting regimes were tested using the Rimbaka timber harvester (RTH) or simply called as Rimbaka. The machine is employed in one type of reduced impact logging (RIL) method. After the harvestings, post-harvest assessments were conducted to determine the impacts of each cutting option on the forest stands. In the assessments, actual damage on the residual trees from the different cutting regimes due to the harvesting operations was assessed. Besides the physical and ecological assessments, financial evaluation was also conducted. These assessments were used to determine the final harvesting regime considered the most suitable for the PSF.

Based on the damage assessments, there were 2,396 trees ≥15 cm dbh in the 100 sampling plots of 50 x 20 m. Out of this number, 2,055 trees (86%) survived and another 341 trees (14%) died. Out of the trees that survived, 1,520 (63%) trees showed no damage at all while 535 (22%) had some damage. Meanwhile, of the trees that died, 396 trees (11%) died due to felling activity and another 67trees (3%) died because of extraction by the Rimbaka. Nonetheless, focus was given to the damage on trees with dbh ≥ 30 cm as these are trees considered as residual stands. All together there were 848 trees ≥ 30 cm dbh in the sample plots, in which 755 (89%) survived and the remaining 93 trees (11%) died. Out of the 755 trees that survived, 546 trees had no damage at all while 209 trees showed some damage on their crowns, stems, roots or their combinations. Interestingly, there were 106 trees of *Callophyllum* spp. (bintangor) and 87 trees of *Gonystylus bancanus* (ramin melawis) that were not damaged at all. Both species are the main commercial timber species of the residual stands. Among those trees that had some kind of damage, 91 trees (44%) had light, 49 trees (23%) medium and 70 trees (33%) serious damage respectively. Trees in the light and medium categories of damage are expected to survive at least for a certain

number of years, while those having serious damage are expected to die within a short time. Based on the assessments, in general tree survival using RIL was high at 86% and 89% for categories of trees with dbh of $\geq$10 cm and $\geq$30 cm respectively. Moreover, a high number of trees that had no damage at all was recorded. In addition, in the case of residual stands (trees $\geq$30 cm), of trees with some kind of damage only about 33% had serious damage that may lead to their mortality. Apart from that, felling was found to be the main reason for mortality at 11% compared to extraction at only 3%. Therefore, it can be concluded that the RIL causes minimum impact on the residual stands and timber extraction contributes only a small portion of trees that die during the harvesting operation.

A yield projection model called Growth and Yield Model for Tropical Peat Swamp Forest (GYMTPSF) is being developed as another output of this study. The GYMTPSF was originally developed for dry inland forest. Calibration has been made on the original software to suit the PSF data and environment. Among others, the GYMTPSF can be used to project stand tables of stocking, basal area, volume and mean annual increments (MAIs). Based on these studies, volume mean MAIs and optimum cutting cycles are projected. The volume MAI for each block is not far different from the next, in the range of 1.75–1.88 $m^3ha^{-1}yr^{-1}$, while the optimum cutting cycle varies in the range of 35–40 years depending on the block.

In terms of timber production, the total timber production in the study area of 100 ha was 8,698.9 m^3. Apparently, due to the lower cutting regime, Block 1 had the highest timber production, followed by Blocks 2, 3 and 4 at 110.5, 106.1, 80.1 and 51.2 m^3ha^{-1} respectively. The total cost of timber harvesting in the study site was RM22,476.70 ha^{-1}. The cost of felling consumed the largest portion of 51.42% followed by administration and pre-felling costs at 46.44 and 2.16% respectively. Based on the financial evaluation, the analysis gave positive net present value (NPV) for timber harvesting in Blocks 1 to 3 but negative value in Block 4. Therefore timber harvesting is viable in Blocks 1, 2 and 3, but not in Block 4. The productivity of the main activities and machinery used in the harvesting operation employing RIL such as felling and haulage was also examined in this study. The hydrological response to road construction and forest logging is also discussed and reported. Last but not least, a local volume table (LVT) was produced to be used for more accurate estimation of *G. bancanus* logs in Pekan FR.

As conclusion, this study has produced outputs that can contribute to optimum harvesting of PSF, in particular for Pekan FR. In terms of cutting limits, this study suggests the cutting limits of Block 3 to be used in the Ramin-Bintangor subtype. The cutting limits are 60 cm for *G. bancanus* and dipterocarps, 50 cm for *Calophyllum* spp. and 45 cm for other species. For cutting cycle, the 40-yr cycle is recommended. Encouragingly, the cutting limits and cycle are being used in the Forest Management Plan for Pekan Forest Reserve prepared by the UNDP/GEF PSF Project. It is hoped that the outputs of this project can be used and contribute to better understanding of the PSF ecosystem in Peninsular Malaysia, mainly for the sustainable utilization of timber resources.

CHAPTER ONE

PROJECT BACKGROUND

By

Ismail Parlan, Ismail Harun & Shamsudin Ibrahim

1.1 INTRODUCTION

This research project was to supplement the UNDP/GEF funded project (MAL/99/G31) on "Conservation and sustainable use of tropical peat swamp forest (PSF) and associated wetland ecosystems" (Anonymous 2003). In general, the UNDP/GEF PSF Project covered aspects of conservation of South East Pahang PSF. Apart from that, there was a study conducted by DANIDA PSF Project on timber assessment in Pekan Forest Reserve (FR). The study has produced report on the forest subtype for Pekan FR based on species composition (Blackett & Wollesen 2005). Eleven forest subtypes have been developed by the study with the Ramin-Bintangor subtype representing about 20% of whole Pekan FR. Ramin (*Gonystylus bancanus*) is the most valuable commercial PSF species that justified the selection of the Ramin-Bintangor subtype area for the present study. This study placed emphasis on optimum harvesting of the PSF in Peninsular Malaysia (Ismail *et al.* 2005) as indicated in Table 1.1.

Table 1.1 Project identification

Title	Optimum harvesting regimes of peat swamp forest in Peninsular Malaysia
Implementing agency	Forest Research Institute Malaysia (FRIM)
Duration	four years, 2005–2008 (including extension)
Project site	Pekan FR, Pahang
Project costs	RM790,000.00 – received from Levy Fund

1.2 PROJECT JUSTIFICATION

It is important to develop a specific management system for PSF based on its own physical and ecological characteristics. Among the significant aspects of forest management is 'optimum harvesting'. Optimum harvesting is critical in achieving sustainable management of all forest types, including the PSF and this can be achieved by assessing the stocking of residual trees. Outputs from this optimum harvesting project could be applied to other productive forest subtypes in the Pekan FR itself. Moreover, outputs from this research project could be extended to other productive PSFs in Selangor and Sarawak. This project is very critical because the outputs would contribute to the development of a management system suitable for the PSF.

The current management system of PSF in Peninsular Malaysia is based on the selective management system (SMS), which was actually developed for the hill forest. Since the stand structure of PSF is different from that of hill forest, the management system needs to be modified to suit the stand conditions in PSF. As reported by Shamsudin (1997a), in general the tree population in PSFs in Pekan, Pahang has three distinct categories: 1) those species that exceed 50 cm dbh size class, 2) tree species that rarely exceed 50 cm dbh and 3) tree species that never exceed 30 cm dbh class. The first population category is represented mainly by valuable timber species like *G. bancanus, Durio carinatus, Palaquium xanthochymum, Madhuca motleyana, Kompassia malaccensis* and *Shorea* spp. that occupy most of the growing space. Individuals of intermediate size classes of these species are very limited. Flowering and fruiting of these species are reasonably good except for *Shorea* spp. that produce fruit irregularly (Nurul Huda 2003, Ismail 2009). After each fruiting season, regeneration is observed to be abundant but the mortality of young seedling is also very high. In the second category of the population in PSF, tree species like *Gymnacranthera eugeniifolia*, *Santiria* spp. and *Polyalthia glauca* are confined mainly to size class below 50 cm dbh, while the third population category is composed mainly of *Quassia indica*, *Antidesma coriaceum*, *Knema intermedia* and *Nephelium maingayi*.

This tree species population structure is assumed to be repeated in other areas in Pekan PSF because the species composition and stand structure in PSF have been found to be homogeneous (Shamsudin 1997a). The character suggests that the PSF in Pekan has more harvestable timber, though with diameter limits rarely exceeding 50 cm dbh for certain species. By promoting more efficient utilization of small-sized lesser-known species from the second and third population structures, through improved processing technologies and marketing strategies, more species could be added to the production list of timbers from PSF (Shamsudin 1997b). Removal of small-sized individuals is also silviculturally desirable as it helps to maintain the proportion of individuals in each population category. This will help to ease pressure on over-harvested commercially important timber species such as *G. bancanus*, *D. carinatus* and *Shorea platycarpa* by imposing higher diameter cutting limits. It is an important feature for sustainable management and biodiversity conservation of PSF in Peninsular Malaysia.

An optimum harvesting regime in PSF can be determined by taking into consideration the population structure and other ecological characteristics where the association and distribution of different tree species are critical factors that need to be considered in the planning process prior to harvesting. Apart from that, economic feasibility is also important in determining the optimum harvesting regime.

1.3 MAIN OBJECTIVES

Main objectives of the project were:

- To examine the stand structure, stocking density, size structure, species composition and tree species distribution in Pekan FR.
- To determine the appropriate cutting limits and cutting cycles for PSF in Pekan FR.

- To evaluate the response of residual trees to and hydrological impacts of roads from harvesting operation.

1.4 GENERAL MATERIALS AND METHODS

1.4.1 Study Site

Compartment 77 in Pekan FR of South Esat Pahang Peat Swamp Forest (SEPPSF) was used as the study site (Figure 1.1). Location of the compartment in Pekan FR is shown in Figure 1.2. The total area of the compartment is about 200 ha. The area is prescribed as Ramin-Bintangor subtype by DANIDA PSF project (Blackett & Wollesen 2005) Although the total study area is about 200 ha, only 100 ha was allocated for the study. The 100 ha was divided to four blocks of 25 ha each, where each block was assigned with different cutting limits (Figure 1.3).

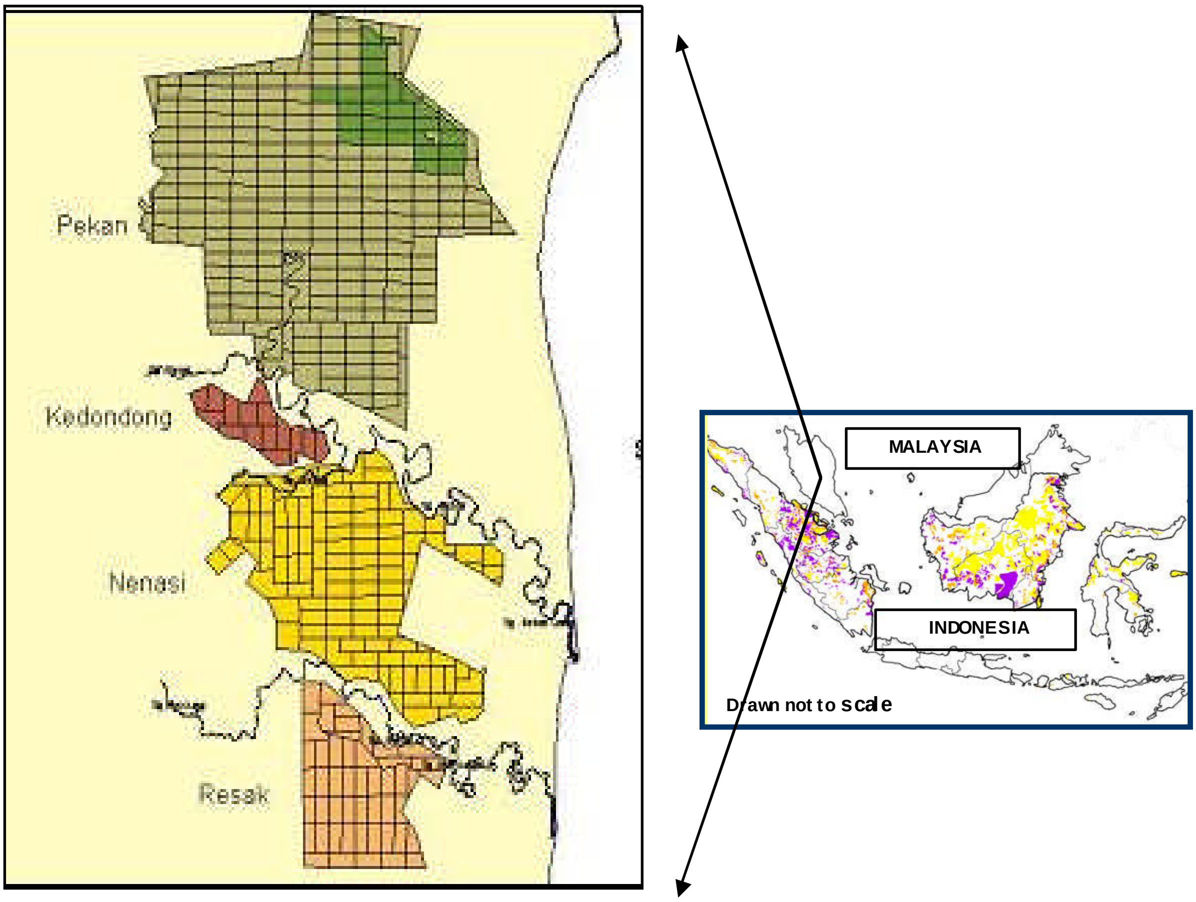
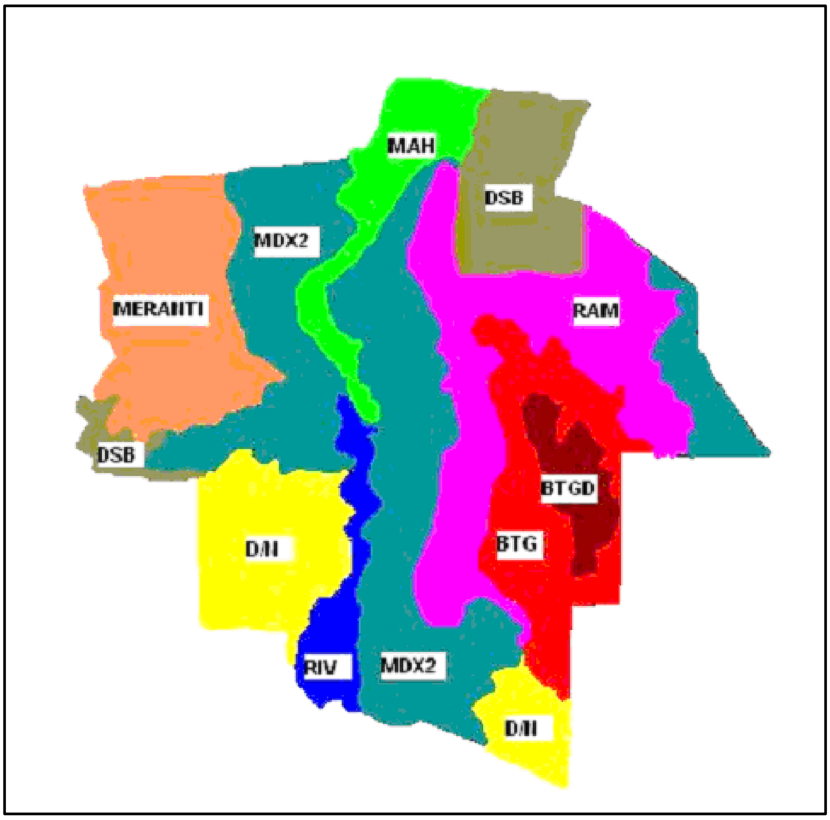


Figure 1.1 Southeast Pahang Peat Swamp Forest (SEPPSF), Peninsular Malaysia



Zone	Abbr.	Forest subtype
1	RAM	Ramin-Bintangor (*Gonystylus-Calophyllum*)
2	MDX2	mixed Kempas-Ramin-Durian (*Koompassia-Gonystylus-Durio*)
3	BTG	Bintangor (*Calophyllum*)
4	BTGD	Bintangor (*Calophyllum*) and Kelat (*Syzygium*)
5	MERANTI	Meranti paya (*Shorea platycarpa*)
6	D/N	Durian-Nyatoh (*Durio-Madhuca*)
7	MAH	Kempas-Mahang-Durian (*Koompassia-Macaranga-Durio*)
8	DSB	Logged/open areas
9	RIV	Riverine/open areas

Figure 1.2 The study site at Pekan FR. The forest subtypes were developed by Blackett and Wollesen (2005) and UNDP/GEF (2006).

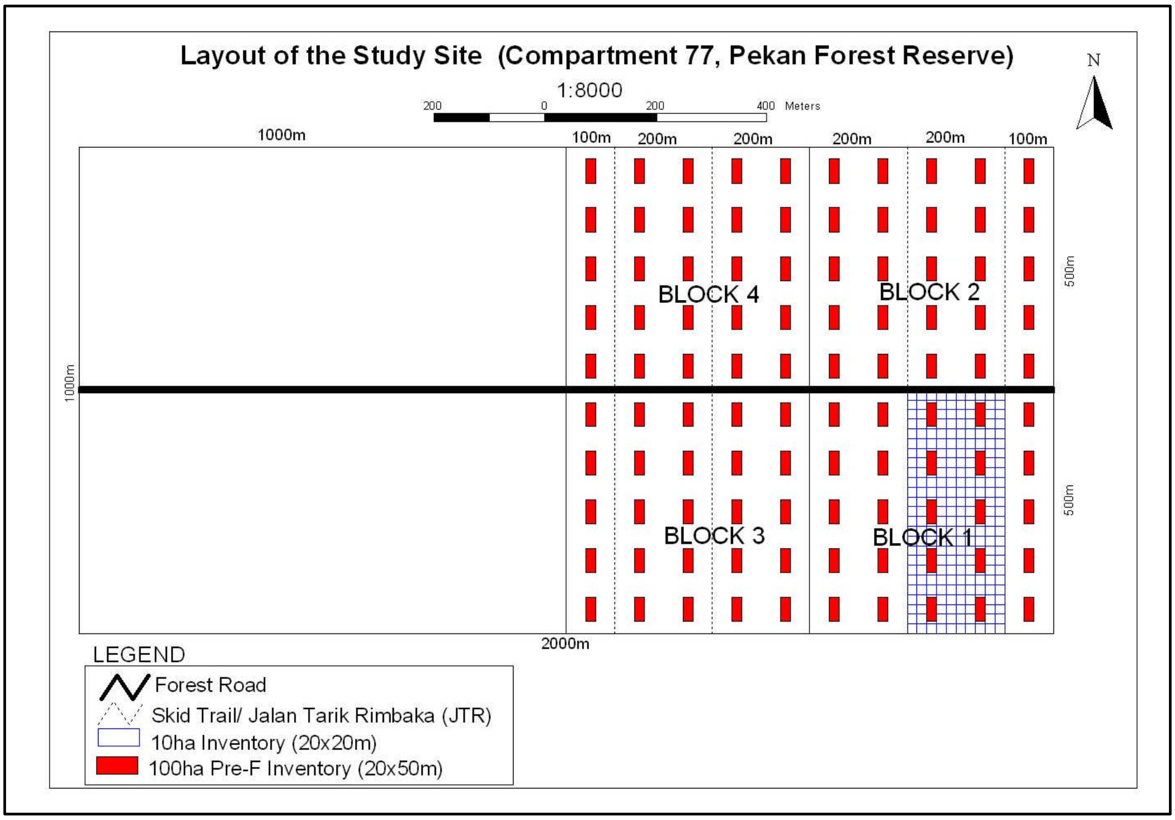


Figure 1.3 Block layout for the cutting regimes trial

1.4.2 Cutting Limit

Based on the pre-felling data and other secondary data (especially to determine the damage factor), several sets of cutting limits were developed (Table 1.2). The detailed procedures to develop the cutting limits are further explained in Chapter 2. The cutting limits were tested on the ground using the Rimbaka timber harvester (RTH). Stand damage, growth, mortality and other factors due to different cutting intensity within each block were monitored throughout the study. The cutting limits were expected to produce various parameters as shown in Table 1.3.

Table 1.2 Selected cutting limits for species group in each harvesting block

Block	**Cutting limits (cm dbh)** **Group 1 – Group 2 – Group 3**	**Description**
1	50 – 45 – 40	Low cutting limit
2	55 – 45 – 40	Medium cutting limit
3	60 – 50 – 45	Medium cutting limit
4	65 – 55 – 50	High cutting limit

Group 1 = *G. bancanus* and dipterocarps only
Group 2 = *Callophyllum* spp. only
Group 3 = other species

Table 1.3 Cutting limits suggested for the four blocks

Cutting option for Groups 1, 2 & 3	**BLOCK 1** $50^a - 45^b - 40^c$	**BLOCK 2** $55^a - 45^b - 40^c$	**BLOCK 3** $60^a - 50^b - 45^c$	**BLOCK 4** $65^a - 55^b - 50^c$
No. of trees (stems ha^{-1}) ≥ 30 cm dbh left after harvesting	42.4	40.0	69.4	64.6
Volume (m^3 ha^{-1}) ≥ 30 cm dbh left after harvesting	34.0	32.8	83.1	75.3
% of ramin ≥ 30 cm dbh before harvesting	22.4	20.5	18.0	19.6
% of ramin ≥ 30 cm dbh left after harvesting	23.0	21.1	18.5	20.9
Total no. of trees harvested based on cutting option (stems ha^{-1})	53.6	46.0	37.2	27.6
Total volume harvested based on cutting option (m^3 ha^{-1})	110.9	102.2	114.7	82.7
Volume of ramin, dipterocarp & bintangor ≥30 cm dbh left after harvesting (m^3 ha^{-1})	20.6	19.7	56.1	52.4
Volume of ramin, dipterocarps & bintangor ≥30 cm dbh harvested (m^3 ha^{-1})	71.3	63.2	50.8	37.8

Notes:

Species group:
1 = Ramin and dipterocarps only
2 = Bintangor species only
3 = other species

Cutting limits:
a = Ramin and dipterocarps only
b = Bintangor species only
c = other species

Block 1 was selected for the lowest cutting limits; the cutting option was predicted to produce a total volume of 110.9 m^3 ha^{-1} with removal of 53.6 stems ha^{-1}. Out of a total volume of 110.9 m^3 ha^{-1} in Block 1, about 71.3 m^3 ha^{-1} or 64% comprised species of ramin, dipterocarps and bintangor. The percentage of ramin before harvesting was about 22.4% and with the cutting limits assigned to Block 1, the expected ramin left in the area after the harvesting was about 23%.

Meanwhile, Block 2 and Block 3 were assigned to represent medium cutting limits. Block 2 was expected to produce about 102.2 m^3 ha^{-1} of which 63.2 m^3 ha^{-1} or 62% were ramin, dipterocarps and bintangor. The number of trees to be cut was about 46 stems ha^{-1}. The percentage of ramin before harvesting was about 20.5% and expected to be slightly increased to 21.1% after harvesting. Block 3 was expected to produce total production of timber about 114.7 m^3 ha^{-1} with less trees cut at about 37.2 stems ha^{-1}. The volume of ramin, dipterocarps and bintangor expected to be harvested was 50.8 m^3 ha^{-1} or about 44% of the total production. The percentages of ramin before and after harvesting were about 18.0% and 18.5% respectively.

Block 4 was assigned with the highest cutting limits. The cutting option was expected to produce about 82.7 m^3 ha^{-1} to 27.9 stems ha^{-1} will be harvested. The volume of ramin, dipterocarps and bintangor expected to be harvested was about 37.8 $m^3 ha^{-1}$ (or about 46% out of the 82.7 $m^3 ha^{-1}$). The percentage of ramin before harvesting was estimated at about 19.6% increasing to 20.9% after harvesting. Generally, the percentages of ramin before and after harvesting remained almost the same in all blocks and the variation in terms of volume harvested was contributed from the extraction of bintangor and other species. Since ramin is the most important commercial species in the PSF, the consideration to maintain its percentage after harvesting is highly crucial.

1.4.3 Pre-felling Inventory and 100% Inventory

A pre-felling (Pre-F) inventory was carried out within the study area. The inventory was conducted to obtain certain forest stand information such as stocking density, size structure, species composition and spatial distribution of trees. Besides the Pre-F inventory, an area of 10 ha was fully inventorized for trees ≥ 30 cm dbh. Results of the 10-ha inventory were used to compare with the Pre-F inventory results. Apart from that, the inventory also produced full information on the spatial distribution of trees ≥ 30 cm in the PSF (for 10-ha area) as shown in Figure 1.4.

Based on the Pre-F and 10-ha inventories, it was found that in terms of volume, ramin and bintangor were the main species occupying the study site. These results confirmed the earlier findings by the DANIDA PSF Project (Blackett & Wollesen 2005). Some main results of both inventories for trees ≥ 30 cm dbh are shown in Table 1.4.

Table 1.4 Main results of Pre-F and 10-ha inventories (≥ 30 cm dbh)

Inventory	**Pre-F**			**10 ha**		
Species category	**Tree ha^{-1}**	**BA/ha (m^2ha^{-1})**	**Vol./ha (m^3ha^{-1})**	**Trees ha^{-1}**	**BA/ha (m^2ha^{-1})**	**Vol./ha (m^3ha^{-1})**
Dip. meranti	4.3	0.8	6.7	7.3	1.5	12.6
Dip. non-meranti	0.1	0.0	0.2	0.8	0.1	0.9
Non-dip. LHW	25.4	3.8	31.2	32.9	5.1	34.4
Non-dip. MHW	32.1	6.0	40.4	38.7	6.9	40.5
Non-dip. HHW	1.8	0.2	2.0	2.6	0.4	2.6
Non-dip. misc.	1.3	0.1	0.8	0.6	0.1	0.4
Ramin	22.1	5.1	53.0	21.6	5.3	48.9
Bintangor	27.7	4.8	42.4	19.2	3.6	26.7
Total	**114.8**	**20.9**	**176.7**	**123.7**	**23.0**	**167.0**

Note:
LHW = light hardwoods
MHW = medium hardwoods
HHW = heavy hardwoods
Misc. = miscellaneous / other species

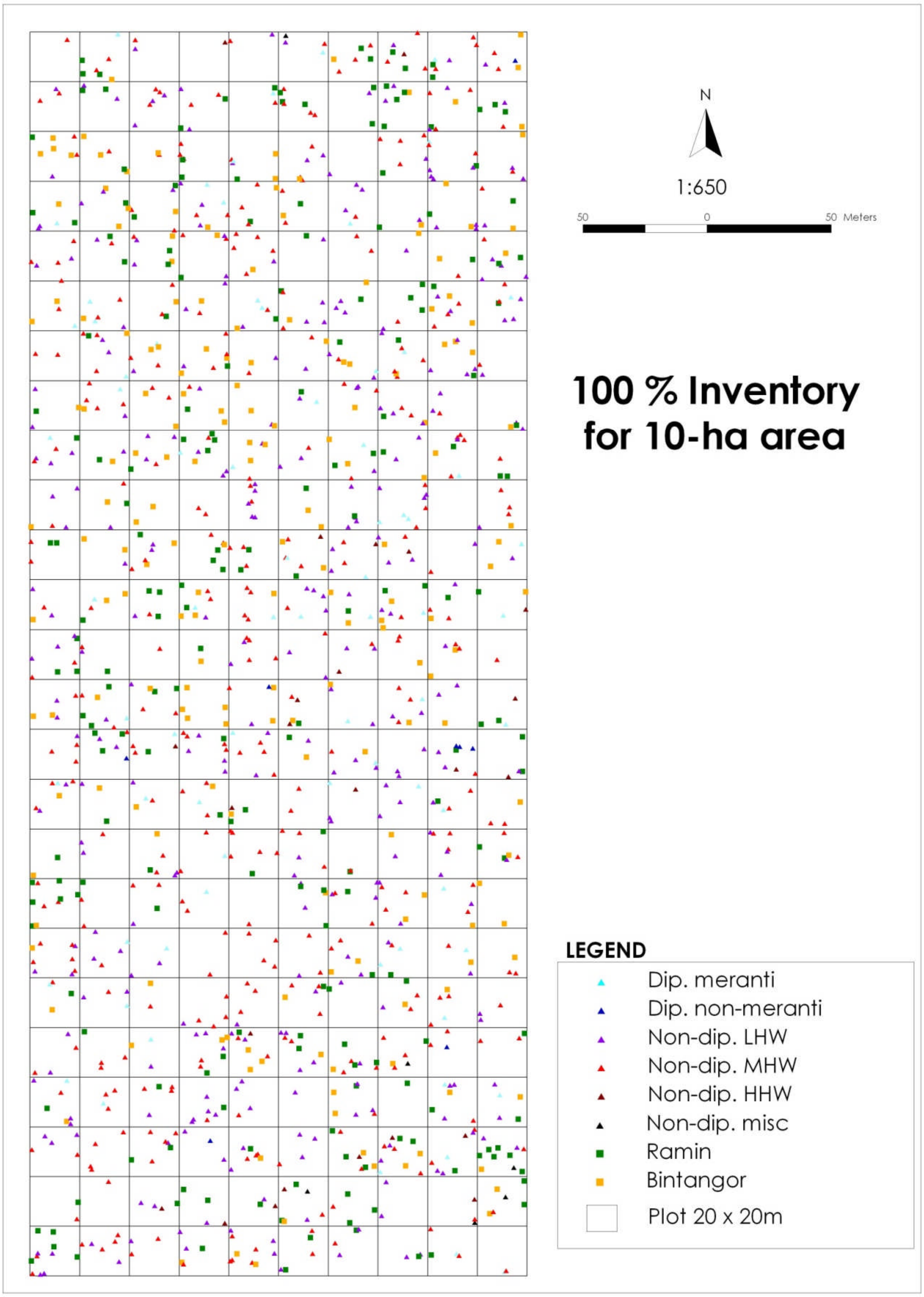


Figure 1.4 Spatial distribution of trees ≥30 cm in Compartment 77, Pekan FR (for 10-ha area)

For the Pre-F inventory, the number of trees was 114.8 stems ha^{-1}, basal area about 20.9 m^2 ha^{-1} and volume 123.7 m^3 $ha^{-1,}$ and for the 10-ha inventory, the corresponding values were 124 stems ha^{-1}, 23.0 m^2 ha^{-1} and 167 m^3 ha^{-1}. The small differences in the results between both inventories were mainly due to different sampling size.

1.4.4 Harvesting System

The RTH is a modified tractor machine with an extended arm and a powerful winching system (Chong & Latifi 2003). It operates the same way as a mobile highlead yarding system (Figure 1.5). A cable can be dragged into the forest from the skid trail, called "jalan tarik Rimbaka" (JTR) and is then attached to the log as far as 150 m away, although its safety extraction distance is 125 m (Elias & Khali Aziz 2008). However, in this study, the extraction distance was fixed at a maximum of 100 m for the purpose of systematic JTR construction, harvesting block division and easier monitoring work.

The log is lifted and then winched to the track by the RTH; the long arm enables the front of the log to be raised off the ground, thereby reducing damage caused by the passage of the log through the forest. Logs extracted by the RTH are placed along the JTR and pulled to a temporary log yard at a forest road by a traxcavator. Then the logs are transported by lorries to a permanent log yard for further processing. The application of the RTH allows harvesting operations with little access for machinery into the forest (apart from forest roads and JTR), thereby reducing the environmental impacts of harvesting. This qualifies logging using the RTH as a reduced impact logging (RIL) system. Details of the RTH in the PSF areas are described in Elias and Khali Aziz (2008). Harvesting operation began in October 2006 and was completed in May 2007. However, the harvesting operation was stopped temporarily from December 2006 to February 2007 due to flooding of the study site during the monsoon season.

Figure 1.5 The Rimbaka timber harvester restricts its movement by pulling logs using a long cable hence minimizing the extraction damage to the forest floor

CHAPTER TWO

DEVELOPMENT OF CUTTING OPTIONS FOR PEAT SWAMP FORESTS

By

Abd Rahman Kassim, Ismail Parlan, Shamsudin Ibrahim, Samsudin Musa, Wan Mohd Shukri Wan Ahmad, Azmi Nordin & Grippin Akeng

2.1 INTRODUCTION

The introduction of mechanized harvesting to peat swamp forest (PSF) has altered the size structure, species composition, spatial distribution and stocking level, and the resulting residual stand has become more heterogeneous. The extent of alteration of forest conditions depends on the method and intensity of harvesting. Proper harvesting planning and execution would avoid extensive damage to the soil and residual stand. Besides the extent of roads, skid-trails and decking sites within the concession area, the intensity of felling in terms of the number and size of trees felled contributes to the residual stand damage. Therefore it is critical for harvesting operation to fit into the silvicultural concept in that it should provide a favourable condition for growth of potential crop trees and the establishment of regeneration (Anonymous 1992).

In principle, the productivity of managed forests can be improved through silvicultural practices such as control of stand structure or developmental processes, control of species composition, control of stand density, restocking of unproductive areas, control of rotation length, facilitation of harvests and conservation of site productivity (Smith *et al.* 1997). The control of stand structure, species composition and stand density are very important determinants of stand productivity and can be manipulated directly by foresters. Harvesting should be regarded as the first silvicultural intervention (Anonymous 1992). In developing the cutting option for PSF, we looked into these three key components of forest stand and used them as the basis to decide the appropriate cutting option.

This chapter describes the development of cutting options to be further selected as appropriate cutting limits for PSF dominated by ramin melawis (*Gonystylus bancanus*) and bintangor gambut (*Callophyllum ferrugineum* var. *ferrugineum*) taking into account the key components of the forest stand.

2.2 MANAGEMENT PRACTICES IN PEAT SWAMP FOREST

The management of PSF currently adopts the selective cutting approach where all trees above a specified diameter limit within a timber species group are felled. The method adopts the Selective Management System (SMS) approach originally developed for inland mixed dipterocarps forest. SMS is the application of cutting regimes over a specified forest area that will yield an economically viable amount of timber while retaining adequate advanced growth for the future harvest in the shortest possible time (Thang 1997).

As the stocking, size structure and major species composition differ, there is a need to look into an alternative method of assessing growing stock appropriate for PSF condition. Without appropriate consideration of the key dominant species of interest, logging may cause irreversible failure to the sustainability of timber production of the species.

2.3 DEVELOPMENT OF CUTTING OPTIONS

A pre-felling (Pre-F) inventory of 10% sampling intensity formed the basis for growing stock assessment under the SMS prior to any prescription of harvesting regimes. After considering adequacy of stocking, species composition and economic cut, an appropriate harvesting regime for the forest type was recommended. The analysis of tree density, basal area and volume per hectare was based on the entire forest area. In actual implementation, the assessment of growing stock should consider only the net production area, i.e. excluding roads, skid-trails, landing sites, buffer zones and sensitive areas of steep slope.

All tree volume calculations for both before and after logging were based on utilizable or net volume. The number of trees per hectare before logging was the actual value, but after logging the actual value was multiplied by a damage factor (Table 2.1).

2.3.1 Damage Factor

Damage factors adopted in the PSF harvesting regime study follow the SMS prescription (Table 2.1):

Table 2.1 Damage factor allometry

Dbh class (cm)	Damage factor (%)
15-30	50
30-45	40
45-60	30
60++	20

Source: JPSM (1997)

2.3.2 Volume Calculation

The gross tree volume was calculated based on the following formula:

Volume (m^3ha^{-1}) = [3.1419 x $(dbh)^2$]/40000 x log length x form factor

As there is no specific volume table for the PSF, we adopted a generalized form factor of 0.65 for all trees (JPSM 1997). The merchantable log length of trees greater than 30 cm dbh was assessed visually, while the trees between 15 and 30 cm were assumed to be 5 m high. The volume is calculated as follows:

Tree volume = stem basal area x log length x form factor

where stem basal area is equal to π*dbh^2/40,000.

For example, if the tree dbh is 40 cm and the log length is 10 m, the volume is calculated as follows:

Stem basal area = 3.142 x 40^2/40,000=0.1256637 m^2

Therefore the tree volume = 0.1256637 x 10 x 0.65=0.816814 m^3

2.3.3 Species Grouping

The Pre-F inventory data were categorized to eight species group, namely (Table 2.2):

Table 2.2 Species grouping used in the development of cutting options

No.	Species group
1	Dipterocarps meranti
2	Dipterocarps non-meranti
3	Light hardwoods other than dipterocarps, ramin & bintangor
4	Medium hardwoods other than dipterocarps, ramin & bintangor
5	Heavy hardwoods other than dipterocarps, ramin & bintangor
6	Miscellanous other than dipterocarps, ramin & bintangor
7	Ramin
8	Bintangor

Ramin and bintangor were treated as their own entities as they are the most dominant species in the area. Information on the species abundance is used in assessing the growing stock in deciding the appropriate cutting limits.

2.4 HARVESTING SIMULATION

A programming code was developed using *R Language* to run the harvesting simulation analysis (Appendix 2.1). The program consisted of five major subprograms:

- Subprogram 1:out.fcd – preparing data set for analysis
- Subprogram 2:out.cut – simulating trees to be cut
- Subprogram 3:out.retain – simulating trees to be retained
- Subprogram 4:out.option – developing cutting option
- Subprogram 5:out.select – selection of cutting option

Subprogram 5 simplified the output of subprogram 4 by selecting the cutting options that fulfilled the desired conditions. The available conditions set were:

(a) Minimum cutting limits:
  - Group 1 (dipterocarps & ramin): 50 cm dbh
  - Group 2 (bintangor): 45 cm dbh
  - Group 3 (other species): 40 cm dbh

(b) Cutting limits of Group 2 are at least 5 cm lower than Group 1
(c) Cutting limits of Group 3 are at least 5 cm lower than Group 2
(d) Proportion of ramin after felling shall be equal or higher than before felling
(e) Minimum number of residual trees required according to the stocking standards of 32 trees ha^{-1}
(f) Maximum harvestable number of trees of 20 trees ha^{-1}
(g) Maximum harvestable volume 85 m^3ha^{-1}

2.5 CASE STUDY: PEKAN FOREST RESERVE

We ran the simulation harvesting based on Pre-F inventory data from a 100-ha study site in Compartment 77, Pekan FR. Examples of the output of the analysis of the selected parameters are shown in Table 2.3. Nineteen cutting options fulfill the minimum stocking standards recommended. The final decision on cutting option depends on the preferences of the forest manager.

From the results, the proposed cutting limits based on the maximum harvestable volume of standing trees of 60.3 m^3ha^{-1} are 65 cm for ramin and dipterocarps, 60 cm for bintangor and 55 cm for other species. If the harvestable number of trees is lowered down to 15 trees, the maximum volume of harvest can be attained at 44.3 m^3ha^{-1} at cutting limits of 70 cm for ramin and dipterocarps, 65 cm for bintangor and 60 cm for other species. The final selection of cutting limts is shown in Table 2.4.

Table 2.3 Selected cutting options based on the prerequisite conditions mentioned

Cutting option (Groups: 1-2-3)	Post-harvest stocking		Proportion of ramin (%)		Expected harvest	
	Number of residual trees (stems ha^{-1})	Volume of residual trees ($m^3 ha^{-1}$)	Pre-harvest	Post-harvest	Number of trees (stems ha^{-1})	Volume of trees ($m^3 ha^{-1}$)
65-60-55	59.3	76.5	20.4	21.3	18.1	60.3
70-60-55	60.4	80.2	20.4	22.6	16.6	55.2
70-65-55	61.7	83.4	20.4	22.2	14.9	50.8
70-65-60	64.0	88.1	20.4	21.4	11.7	44.3
75-60-50	59.3	82.2	20.4	24.9	18.7	54.3
75-60-55	61.8	86.1	20.4	23.9	15.1	48.5
75-65-55	63.0	89.3	20.4	23.5	13.4	44.2
75-65-60	65.3	94.0	20.4	22.6	10.2	37.7
75-70-60	65.6	94.8	20.4	22.6	9.9	36.6
75-70-65	67.7	100.1	20.4	21.9	6.7	28.1
80-60-50	59.9	85.2	20.4	25.6	18.0	50.6
80-60-55	62.3	89.1	20.4	24.6	14.4	44.8
80-65-55	63.6	92.3	20.4	24.1	12.7	40.5
80-65-60	65.9	97.0	20.4	23.3	9.5	34.0
80-70-60	66.1	97.8	20.4	23.2	9.2	32.9
85-65-55	63.8	93.1	20.4	24.3	12.5	39.5
85-65-60	66.1	97.8	20.4	23.5	9.3	32.9
85-70-60	66.3	98.6	20.4	23.4	9.0	31.9
90-70-60	66.5	99.7	20.4	23.6	8.8	30.5

Note: Group 1 = *G. bancanus* and dipterocarps only, Group 2 = *Callophyllum* spp. only, Group 3 = other species

Table 2.4. Final selection of cutting limits for species group

Block	Cutting limits (cm dbh) Group 1 – Group 2 – Group 3	Description
1	50 – 45 – 40	Low cutting limits
2	55 – 45 – 40	Medium cutting limits
3	60 – 50 – 45	Medium cutting limits
4	65 – 55 – 50	High cutting limits

Note:
Group 1 = *G. bancanus* and dipterocarps only
Group 2 = *Callophyllum* spp. only
Group 3 = other species

2.6 CONCLUSIONS

We have demonstrated the development of cutting options for PSF dominated by ramin and bintangor. Nineteen cutting options are available for selection by the forest manager that fulfill the minimum stocking standards for PSF dominated by ramin and bintangor. The cutting options available depend on the conditions set for selection. We may add new conditions where necessary. For example:

- number of key species (e.g. ramin) residual trees to be retained;
- number of large-sized parent trees to be retained.

The cutting options will vary according to the initial stocking, size structure and targeted species composition of the PSF. At the end, four sets of cutting limits were selected to be used in this study in determining appropriate cutting limits for the PSF. Better representation of the key dominant species retention for future crops can be better achieved when development of cutting options takes into account the stand conditions.

Appendix 2.1 Programming code using *R Language* for simulation analysis

i) Installation of R Language Software

Install R open-source software
Open R program
On the File Menu, click the change working directory sub-menu
Set your working directory to where you place the source code
Type the source code at the R console"

source("option2 New Cutting Regime Generic.ver3_2011.r") [1]

To run analysis type the following

out.select() [2]

You may set condition of your output
(a) Number of residual to be retained:noresidual
(b) Maximu harvestable number of trees: Harvest.tph
(c) Minimum harvest of volume: Harvest.V.min
(d) Maximum harvestable volume: Harvest.V.max

out.select(noresidual=32,Harvest.tph=20,Harvest.V.min=30,Harvest.V.max=100) [3]

Type of output
Three output file will be produced;
(a) All cutting option output display
(b) Selected cutting option output based on the set condition. See [3]
(c) as (B) with only selected column
no = Number
option = Cutting option (Dipterocarp&Ramin/Bintangor/Non-dipterocarp)
post.T30 = Total number of residual trees
post.V30 = Total residual volume
PRpre.T30 = Percentage ramin before felling (>30cm dbh)
PRpost.T30 = Percentage ramin after felling (>30cm dbh)
H.T = Total number of trees harvested
H.V = Total volume harvested
#ratio = Ratio of volume harvested to volume before felling

ii) Data preparation using R Language Program

```
out.psf=function(plot="sp100",block="all")
{
setwd("C:/ARK/5-Research Projects/Peat Swamp Forest/Harvesting regime/Data") #
Example of a directory of data file

spplist=read.table("Master list-PSF species.txt",header=T,sep="\t")
```

```
if (plot=="sp145") plot.dat=read.table("plot pre F (blocking).txt",sep="\t",header=T)
if (plot=="sp100") plot.dat=read.table("plot pre F (blocking 100ha).txt",sep="\t",header=T)

if(block=="all")    plot.dat=plot.dat
if(block=="block1.old") plot.dat=subset(plot.dat,plot.dat[,7]==1)
if(block=="block2.old") plot.dat=subset(plot.dat,plot.dat[,7]==2)
if(block=="block3.old") plot.dat=subset(plot.dat,plot.dat[,7]==3)
if(block=="block4.old") plot.dat=subset(plot.dat,plot.dat[,7]==4)

if(block=="all")    plot.dat=plot.dat
if(block=="block1.new") plot.dat=subset(plot.dat,plot.dat[,8]==1)
if(block=="block2.new") plot.dat=subset(plot.dat,plot.dat[,8]==2)
if(block=="block3.new") plot.dat=subset(plot.dat,plot.dat[,8]==3)
if(block=="block4.new") plot.dat=subset(plot.dat,plot.dat[,8]==4)
plot.dat=plot.dat[c(-1,-2,-3),]

if (plot=="sp100")
names(plot.dat)=c("tahun","negeri","nohs","nokomp","nogaris","nopetak","bloklama","blokb
ar","palma","resam","nopetakkecil","nopokok","kodsp","jenis","dbh","bil","klt","subur","dpp
j","lppj","ptk2x2")

if (plot=="sp145")
names(plot.dat)=c("tahun","negeri","nohs","nokomp","nogaris","nopetak","bloklama","blokb
ar",
"palma","resam","nopetakkecil","nopokok","kodsp","jenis","dbh","bil","klt","subur","dppj","l
ppj")

aa=merge(plot.dat,spplist,by="kodsp")

###### based on log assessment from nearby site #####
aa$bil=as.numeric(as.character(as.factor(aa$bil)))
aa$dbh=as.numeric(as.character(as.factor(aa$dbh)))

#aa$bil=ifelse(aa$dbh>=30&aa$dbh<40&aa$bil=="",2.2,aa$bil)
#aa$bil=ifelse(aa$dbh>=40&aa$dbh<50&aa$bil=="",2.7,aa$bil)
#aa$bil=ifelse(aa$dbh>=50&aa$dbh<60&aa$bil=="",2.8,aa$bil)
#aa$bil=ifelse(aa$dbh>=60&aa$dbh<70&aa$bil=="",2.9,aa$bil)
#aa$bil=ifelse(aa$dbh>=70&aa$dbh<80&aa$bil=="",2.5,aa$bil)
#aa$bil=ifelse(aa$dbh>=80&aa$dbh<90&aa$bil=="",2.2,aa$bil)
#aa$bil=ifelse(aa$dbh>=90&aa$bil=="",2.6,aa$bil)

#################aa$bil#####

petak=paste(aa$nogaris,aa$nopetak,sep="-")
aa$dbh=as.numeric(as.character(as.factor(aa$dbh)))
```

```
dlog=as.numeric(as.character(as.factor(aa$bil)))*5
bat=aa$dbh*aa$dbh*pi/40000
volt=dlog*bat*0.65
volt=ifelse(aa$dbh>=15&aa$dbh<30,5*bat*0.65,volt)

expan30=1/0.10  # expansion factor for different plot size
expan15=1/0.05
expan5=1/0.01
expan=ifelse( aa$dbh>=5&aa$dbh<15, expan5,0)
expan=ifelse( aa$dbh>=15&aa$dbh<30, expan15,expan)
expan=ifelse( aa$dbh>30, expan30,expan)

tph=expan
bah=bat*expan
volh=volt*expan

# damage

dampct=cut(aa$dbh,c(14.9,29.9,44.9,59.9,10000))
dampct=ifelse(aa$dbh>14.9&aa$dbh<30,0.19,0)
dampct=ifelse(aa$dbh>29.9&aa$dbh<45,0.22,dampct)
dampct=ifelse(aa$dbh>44.9&aa$dbh<60,0.13,dampct)
dampct=ifelse(aa$dbh>59.9,0.056,dampct)

psf.dat=data.frame(petak=petak,kodsp=aa$kodsp,kodkom2=aa$kodkom2,dbh=aa$dbh,bil=aa
$bil,dlog=dlog, dampct=dampct,tph=tph,bah=bah,volh=volh)

return(psf.dat)
}

#CUTTING OPTION
#HARVEST

out.cut=function(cut.1=50,cut.2=50,cut.3=50,cut.4=50,cut.5=50,cut.6=50,cut.7=50,cut.8=50)
{
a1=subset(psf.dat,dbh>cut.1 & kodkom2==1)
a2=subset(psf.dat,dbh>cut.2 & kodkom2==2)
a3=subset(psf.dat,dbh>cut.3 & kodkom2==3)
a4=subset(psf.dat,dbh>cut.4 & kodkom2==4)
a5=subset(psf.dat,dbh>cut.5 & kodkom2==5)
a6=subset(psf.dat,dbh>cut.6 & kodkom2==6)
a7=subset(psf.dat,dbh>cut.7 & kodkom2==7)
a8=subset(psf.dat,dbh>cut.8 & kodkom2==8)

sample=length(unique(psf.dat$petak))
```

```
a.dat=rbind(a1,a2,a3,a4,a5,a6,a7,a8)


a.dat$kod=c(a1=rep("a1",dim(a1)[1]),a2=rep("a2",dim(a2)[1]),a3=rep("a3",dim(a3)[1]),a4=re
p("a4",dim(a4)[1]),a5=rep("a5",dim(a5)[1]),a6=rep("a6",dim(a6)[1]),a7=rep("a7",dim(a7)[1])
,a8=rep("a8",dim(a8)[1]))

## All trees
	c4=sum(psf.dat$tph,na.rm=T)/sample;c4=round(c4,2)
	c5=sum(psf.dat$bah,na.rm=T)/sample;c5=round(c5,2)
	c6=sum(psf.dat$volh,na.rm=T)/sample;c6=round(c6,2)
## Cut by kodkom
	b1=tapply(a.dat$tph,a.dat$kod,sum,na.rm=T)/sample;b1=round(b1,2)
	b2=tapply(a.dat$bah,a.dat$kod,sum,na.rm=T)/sample;b2=round(b2,2)
	b3=tapply(a.dat$volh,a.dat$kod,sum,na.rm=T)/sample;b3=round(b3,2)
## All cut
	b4=sum(a.dat$tph,na.rm=T)/sample;b4=round(b4,2)
	b5=sum(a.dat$bah,na.rm=T)/sample;b5=round(b5,2)
	b6=sum(a.dat$volh,na.rm=T)/sample;b6=round(b6,2)
## Pct All cut
	b7=100*b4/c4;b7=round(b7,2)
	b8=100*b5/c5;b8=round(b8,2)
	b9=100*b6/c6;b9=round(b9,2)

# Group 1+ Group 2 in volume before and after
	gp12.dat=subset(a.dat,kodkom2==1| kodkom2==2|kodkom2==7|kodkom2==8)
	c6=sum(gp12.dat$volh,na.rm=T)/sample

	return(list(tph.cut=b1,bah.cut=b2,volh.cut=b3,
	all5above=c(tph=c4,bah=c5,volh=c6),
	allcut=c(tph=b4,bah=b5,volh=b6),
	pctcut=c(tph=b7,bah=b8,volh=b9),
	volgpcut=c6))
}
#CUTTING OPTION
#RETENTION

out.retain=function(cut.1=50,cut.2=50,cut.3=50,cut.4=50,cut.5=50,cut.6=50,cut.7=50,cut.8=5
0)
{
psf.dat$tph.dam=psf.dat$tph*psf.dat$dampct
psf.dat$bah.dam=psf.dat$bah*psf.dat$dampct
psf.dat$volh.dam=psf.dat$volh*psf.dat$dampct

a1=subset(psf.dat,dbh>=30&dbh<cut.1 & kodkom2==1)
a2=subset(psf.dat,dbh>=30&dbh<cut.2 & kodkom2==2)
```

```
a3=subset(psf.dat,dbh>=30&dbh<cut.3 & kodkom2==3)
a4=subset(psf.dat,dbh>=30&dbh<cut.4 & kodkom2==4)
a5=subset(psf.dat,dbh>=30&dbh<cut.5 & kodkom2==5)
a6=subset(psf.dat,dbh>=30&dbh<cut.6 & kodkom2==6)
a7=subset(psf.dat,dbh>=30&dbh<cut.7 & kodkom2==7)
a8=subset(psf.dat,dbh>=30&dbh<cut.8 & kodkom2==8)

sample=length(unique(psf.dat$petak))
a.dat=rbind(a1,a2,a3,a4,a5,a6,a7,a8)

###########################

a.dat$kod=c(a1=rep("a1",dim(a1)[1]),a2=rep("a2",dim(a2)[1]),a3=rep("a3",dim(a3)[1]),a4=re
p("a4",dim(a4)[1]),a5=rep("a5",dim(a5)[1]),a6=rep("a6",dim(a6)[1]),a7=rep("a7",dim(a7)[1])
,a8=rep("a8",dim(a8)[1]))

## Retain by kodkom
	b1=tapply(a.dat$tph,a.dat$kod,sum,na.rm=T)/sample;b1=round(b1,2)
	 b2=tapply(a.dat$bah,a.dat$kod,sum,na.rm=T)/sample;b2=round(b2,2)
	b3=tapply(a.dat$volh,a.dat$kod,sum,na.rm=T)/sample;b3=round(b3,2)

###########################

## Determine no residual trees

   # All trees
		b4=sum(a.dat$tph,na.rm=T)/sample
		b5=sum(a.dat$bah,na.rm=T)/sample
		b6=sum(a.dat$volh,na.rm=T)/sample
   # All damage
		b7=sum(a.dat$tph.dam,na.rm=T)/sample  # damage sum
		b8=sum(a.dat$bah.dam,na.rm=T)/sample
		b9=sum(a.dat$volh.dam,na.rm=T)/sample
   # All undamage
	b10=b4-b7
	b11=b5-b8
	b12=b6-b9

## Determine Ramin pct before and after cutting
ramin.dat=subset(a.dat,kodkom2==7)
# Ramin all
	c4=sum(ramin.dat$tph,na.rm=T)/sample
	c5=sum(ramin.dat$bah,na.rm=T)/sample
	c6=sum(ramin.dat$volh,na.rm=T)/sample
# Ramin damage
	c7=sum(ramin.dat$tph.dam,na.rm=T)/sample
```

```
        c8=sum(ramin.dat$bah.dam,na.rm=T)/sample
        c9=sum(ramin.dat$volh.dam,na.rm=T)/sample
# Ramin undamage
        c10=c4-c7
        c11=c5-c8
        c12=c6-c9
   #% Ramin before
                c13=100*c4/b4 # pct Ramin All
                c14=100*c5/b5
                c15=100*c6/b6
   #% Ramin after
                c16=100*c10/b10 # pct Ramin Residual
                c17=100*c11/b11
                c18=100*c12/b12

# Group 1+ Group 2 in volume before and after

gp12.dat=subset(a.dat,kodkom2==1| kodkom2==2|kodkom2==7|kodkom2==8)
c6=sum(gp12.dat$volh,na.rm=T)/sample
c9=sum(gp12.dat$volh.dam,na.rm=T)/sample
c12=c6-c9

b4=round(b4,2)
b5=round(b5,2)
b6=round(b6,2)
b10=round(b10,2)
b11=round(b11,2)
b12=round(b12,2)
c13=round(c13,2)
c14=round(c14,2)
c15=round(c15,2)
c16=round(c16,2)
c17=round(c17,2)
c18=round(c18,2)

 return(list(tph.retain=b1,bah.retain=b2,volh.retain=b3,
allpre=c(tph=b4,bah=b5,vol=b6),
allpost=c(tph=b10,bah=b11,volh=b12),
pctpreRamin=c(tph=c13,bah=c14,volh=c15),
pctpostRamin=c(tph=c16,bah=c17,volh=c18), volgppost=c12))
}

#Determine the ratio of group 1+group2 cut and retain

out.cut.retain=function(c1=50,c2=50,c3=50)
{
```

```
opsyen=paste(c(c1,c2,c3),sep="-")
cut.dat=out.cut(c1,c1,c3,c3,c3,c3,c1,c2)
retain.dat=out.retain(c1,c1,c3,c3,c3,c3,c1,c2)
Parameter=c("had tebang","bil tebang","isipadu tebang","bil ramin tebang","isipadu ramin tebang","bil bn tebang",isipadu bn tebang","bil tinggal","bil ramin tinggal","bil bn tinggal","vol.ratio=tinggal/tebang")

Nilai=c(opsyen,allcut.tph=cut.dat$allcut$tph,allcut.tph=cut.dat$allcut$volh,ramincut.tph=cut.dat$tph.cut$a7,bncut.tph=cut.dat$tph.cut$a7,ramincut.volh=cut.dat$volh.cut$a7,bncut.volh=cut.dat$volh.cut$a7,raminretain.tph=retain.dat$tph.retain$a7,bnretain.tph=retain.dat$tph.retain$a8,raminretain.volh=retain.dat$volh.retain$a7,bnretain.volh=retain.dat$volh.retain$a8,vol.ratio=retain.dat$volgppost/cut.dat$volgpcut)

out.dat=data.frame(Parameter,Nilai)
return(out.dat)
}
#CUTTING OPTION
#SELECT OPTION

out.option=function()
{
out.option=c()
for (i in 1:72)
{
cut.a=seq(50,90,5)

a1=rep(c(cut.a,cut.a,cut.a,cut.a),2)  # D
a2=rep(c(cut.a,cut.a,cut.a,cut.a),2)  # D
a3=c(cut.a-10,cut.a-15,cut.a-20,cut.a-25,cut.a-15,cut.a-20,cut.a-25,cut.a-30)
a4=c(cut.a-10,cut.a-15,cut.a-20,cut.a-25,cut.a-15,cut.a-20,cut.a-25,cut.a-30)
a5=c(cut.a-10,cut.a-15,cut.a-20,cut.a-25,cut.a-15,cut.a-20,cut.a-25,cut.a-30)
a6=c(cut.a-10,cut.a-15,cut.a-20,cut.a-25,cut.a-15,cut.a-20,cut.a-25,cut.a-30)
a7=rep(c(cut.a,cut.a,cut.a,cut.a),2)
a8=rep(c(cut.a-5,cut.a-10,cut.a-15,cut.a-20),2)

b1=out.retain(a1[i],a2[i],a3[i],a4[i],a5[i],a6[i],a7[i],a8[i])$allpre
b2=out.retain(a1[i],a2[i],a3[i],a4[i],a5[i],a6[i],a7[i],a8[i])$allpost
b3=out.retain(a1[i],a2[i],a3[i],a4[i],a5[i],a6[i],a7[i],a8[i])$pctpreRamin
b4=out.retain(a1[i],a2[i],a3[i],a4[i],a5[i],a6[i],a7[i],a8[i])$pctpostRamin
b5=out.cut(a1[i],a2[i],a3[i],a4[i],a5[i],a6[i],a7[i],a8[i])$allcut
b6=out.cut(a1[i],a2[i],a3[i],a4[i],a5[i],a6[i],a7[i],a8[i])$pctcut
b7=out.retain(a1[i],a2[i],a3[i],a4[i],a5[i],a6[i],a7[i],a8[i])$volgppost
b8=out.cut(a1[i],a2[i],a3[i],a4[i],a5[i],a6[i],a7[i],a8[i])$volgpcut

c1=c(i,b1,b2,b3,b4,b5,b6,b7,b8)
cat("Doing simulation",i,"/", 72, "\n")
```

```
rm(a1,a2,a3,a4,a5,a6,a7,a8,b1,b2,b3,b4,b5,b6,b7,b8)

out.option=data.frame(rbind(out.option,c1))
}
cut=data.frame(out.option)
names(cut)=c("no","pre.T30","pre.B30","pre.V30","post.T30","post.B30","post.V30","PRpre.
T30","PRpre.B30","PRpre.V30","PRpost.T30","Ppost.B30","PRpost.V30","H.T","H.B","H.V
","PH.T","PH.B","PH.V","postVG12.30","cutVG12")

 cut=round(cut,1)
cut.a=seq(50,90,5)
#                a1=c(cut.a,cut.a,cut.a,cut.a)    # Ramin & Dipterocarp
 #               a2=c(cut.a-5,cut.a-10,cut.a-15,cut.a-20)  # Bintangor
#                a3=c(cut.a-10,cut.a-15,cut.a-20,cut.a-25)# Non-dipterocarp
                 a1=rep(cut.a,8)          # Ramin & Dipterocarp
                 a2=rep(c(cut.a-5,cut.a-10,cut.a-15,cut.a-20),2)  # Bintangor
                 a3=c(cut.a-10,cut.a-15,cut.a-20,cut.a-25,cut.a-15,cut.a-20,cut.a-25,cut.a-30)#

Non-dipterocarp
option=paste(a1,a2,a3,sep="-")

final.option=cbind(option,cut)

return(final.option)
}
# Select option

out.select=function(noresidual=32,Harvest.tph=100,Harvest.V.min=30,Harvest.V.max=100)
 {
 option=out.option()
 #psf.dat[1805,6]=10 # correction to more resonable figure of dlog
select=subset(option,PRpost.T30>=PRpre.T30
&post.T30>=noresidual&H.T<Harvest.tph&H.V>Harvest.V.min & H.V<Harvest.V.max)
select=option[,c(2,1,6,8,9,12,15,17,21,22)]
select$ratio=select$postVG12.30/select$cutVG12
select$ratio=round(select$ratio,2)
select.par=select[,c(1:8,11)]
return(list(option=option,select=select, select.par=select.par))
}
message("#################################################################
###########")
message("                HARVESTING REGIME OPTION FOR PSF")
message("Program: out.select(noresidual,Harvest.tph,Harvest.V.min,Harvest.V.max")
message("   Based on New Species Group
D,ND,NDLHW,NDMHW,NDHHW,ND,MISC,Ramin,BN")
message("          Group 1(D,Ramin) Group2(Bintangor) Group 3(ND)")
```

```
message("                    Create psf.dat file by out.psf")
message("#####################################################################
###########")

#Graph of size distribution

out.psf.graph=function()
{
aa=psf.dat
dcat=cut(aa$dbh,c(5,15,30,45,60,75,1000),right=F)
plotno=length(unique(aa$petak))
a1=tapply(aa$tph,dcat,sum,na.rm=T)/plotno
a2=tapply(aa$bah,dcat,sum,na.rm=T)/plotno
a3=tapply(aa$volh,dcat,sum,na.rm=T)/plotno

win.graph()
par(mfrow=c(3,1))
par(mai=c(0.3,0.5,0.1,0.1))
barplot(a1,beside=TRUE,axes=F,ylab="Stems per hectare",ylim=c(0,500));box();axis(side=2)
        barplot(a2,beside=TRUE,axes=F,ylab="Basal area per
hectare",ylim=c(0,15));box();axis(side=2)
        par(mai=c(0.3,0.5,0.1,0.1))
        barplot(a3,xlab="dbh class in cm",beside=TRUE,ylab="Volume per
hectare",ylim=c(0,100));box();axis(side=2)

a1=tapply(aa$tph,list(aa$kodkom2,dcat),sum,na.rm=T)/plotno
a2=tapply(aa$bah,list(aa$kodkom2,dcat),sum,na.rm=T)/plotno
a3=tapply(aa$volh,list(aa$kodkom2,dcat),sum,na.rm=T)/plotno

#leg=c(1,2,3,4,5,6,7,8)
leg=c("DM","DNM","NDLHW","NDMHW","NDHHW","NDMISC","RAMIN","BN")
win.graph()
par(mfrow=c(3,1))
par(mai=c(0.3,0.5,0.1,0.1))

barplot(a1,beside=TRUE,col=1:8,axes=F,ylab="Stems per
hectare",ylim=c(0,250));box();axis(side=2)
barplot(a2,beside=TRUE,col=1:8,axes=F,ylab="Basal area per
hectare",ylim=c(0,4));box();axis(side=2)
par(mai=c(0.3,0.5,0.1,0.1))
barplot(a3,xlab="dbh class in cm",beside=TRUE,col=1:8,ylab="Volume per
hectare",ylim=c(0,40));box();axis(side=2)
legend(2,35,col=1:8,legend=leg,fill=1:8)

setwd("C:/ARK/5-Research Projects/Peat Swamp Forest/Harvesting regime/Results")
write.table(a1,"tphbydclas.txt")
```

```
write.table(a2,"bahbydclas.txt")
write.table(a3,"volhbydclas.txt")

return(list(tph=round(a1,1),bah=round(a2,2),volh=round(a3,2)))
}
psf.dat<-out.psf()
```

CHAPTER THREE

IMPACT OF REDUCED IMPACT LOGGING SYSTEM ON RESIDUAL TREES IN PEAT SWAMP FORESTS

By

Ismail Parlan, Abd Rahman Kassim, Mohd Nizam Mohd Said, Wan Mohd Shukri Wan Ahmad, Samsudin Musa, Ismail Talib & Grippin Akeng

3.1 INTRODUCTION

The only harvesting machine used in Pekan Forest Reserve (FR) is the Rimbaka timber harvester (RTH), popularly called Rimbaka. The machine was developed by Syarikat Upayapadu Sdn. Bhd. and employs the reduced impact logging (RIL) system as described by Elias and Khali Aziz (2008). Since 1999, RIL has been the only system used for timber harvesting in Pekan FR (Forestry Department of Pahang 2006). Therefore, the same RIL system using Rimbaka was used in this study. In general, the main objective of this study was to determine the impacts of the RIL system on the residual trees as applied in the Pekan FR.

3.2 MATERIALS AND METHODS

Compartment 77 in Pekan FR was used as the study site as described in Chapter 1. All blocks were given similar treatments with respect to the RIL system, the only difference being the cutting limits for each block.

An assessment of the damage to residual trees was carried out immediately after completion of the harvesting in all blocks. Assessment was done on the residual trees of ≥15 cm dbh using the same 20 x 50 m Pre-F inventory plots. Undamaged trees were also recorded.

Damage was categorized into three categories based on damage to crowns, stems (including bark), and roots (including buttress). The degree of the damage was categorized into four categories: undamaged, light, medium and heavy damage. Light damage implies that the residual tree will be able to recover and grow as a normal tree, medium refers to damage that will possibly affect growth of the residual tree, while heavy damage will ultimately cause mortality to the tree. The damage was based on the classification used by Wan Mohd Shukri *et al.* (2000), with some modification for the PSF environment. The criteria used to classify damage classes for residual trees are given in Table 3.1. Data analysed in this paper are presented as 'total' (based on the 25 ha of each block) because there was no replication of the cutting limits, as they already covered a large area of 100 ha considered as a real production size in the harvesting of the PSF.

Table 3.1 Degree of damage on residual trees

Type of damage	Undamaged	Light damage	Medium damage	Heavy damage
Crown	0 = not broken	1 = broken < 25%	2 = broken 25 – 50%	3 = broken > 50%
Stem	0 = no scratch	1 = scratched	2 = scraped < 2 m	3 = broken/ fractured/split
Root	0 = not affected	1 = affected < 25%	2 = affected 25 – 50%	3 = affected > 50%

3.3 RESULTS AND DISCUSSION

3.3.1 Actual Log Production

Table 3.2 shows the actual log production based on harvesting blocks in the study area. The total log production was 8,698.9 m^3 from 3,684 harvested trees. The total log production for Blocks 1, 2, 3 and 4 were 2,763.2, 2,653.5, 2,002.7 and 1,279.5 m^3 ha^{-1} respectively. On average, about 87.0 m^3 ha^{-1} of logs of all species were harvested from the study site.

Table 3.2 Actual log productions

Log production	Total volume (m^3) (Total number of trees)	Average (m^3 ha^{-1}) (Average number of trees)
Block 1 (25 ha)	2,763.2 (1,287)	110.5 (51.5 stems ha^{-1})
Block 2 (25 ha)	2,653.5 (1,078)	106.1 (43.1 stems ha^{-1})
Block 3 (25 ha)	2,002.7 (851)	80.3 (34.0 stems ha^{-1})
Block 4 (25 ha)	1,279.5 (468)	51.2 (18.7 stems ha^{-1})
Total (100 ha)	8,698.9 (3,684)	87.0 (36.8 stems ha^{-1})

3.3.2 Damage on Residual Trees

Results of damage assessment after the completion of harvesting operations are shown in Table 3.3. There were a total of 547, 547, 643 and 659 trees of $\geq$15 cm dbh recorded in Blocks 1, 2, 3 and 4 respectively. The total numbers of trees that survived were 467 (85.4%), 468 (85.6%), 538 (83.7%) and 582 (88.3%) for Blocks 1, 2, 3 and 4 respectively. Thus, the total numbers of trees that died for all species for Blocks 1, 2, 3 and 4 were 80 (14.6%), 79 (14.4%), 105 (16.3%) and 77 (11.7%) respectively.

The total numbers of survived trees of all species that were undamaged were 318 (58.1%), 315 (57.6%), 427 (66.4%) and 460 (69.8%) in the respective blocks. The numbers of survived trees that suffered various degrees of damage were 149 (27.2%), 153 (28.0%), 111 (17.3%) and 122 (18.5%) for Blocks 1, 2, 3 and 4 respectively.

Table 3.3 Tree damage assessment (≥ 15 cm dbh)

Parameter	**Block 1**	**Block 2**	**Block 3**	**Block 4**
Total number of trees surveyed	547	547	643	659
Total number of trees that died	80	79	105	77
Percentage (%)	14.6	14.4	16.3	11.7
Total number of trees that survived	467	468	538	582
Percentage (%)	85.4	85.6	83.7	88.3
Total number of trees that survived with various degrees of damage	149	153	111	122
Percentage (%)	27.2	28.0	17.3	18.5
• Total number of trees with heavy damage	66	63	72	70
• Percentage (%)	12.1	11.5	11.2	10.6
• Total number of trees with medium damage	58	43	21	22
• Percentage (%)	10.6	7.9	3.3	3.3
• Total number of trees with light damage	25	47	18	30
• Percentage (%)	4.6	8.6	2.8	4.6
Total number of undamaged trees	318	315	427	460
Percentage (%)	58.1	57.6	66.4	69.8

Table 3.4 shows the survived trees in different dbh classes. All species of smaller dbh classes illustrate a high number of survived trees. The results were expected as the smaller DBH classes represent the major number of trees in the study area.

Table 3.4 Total numbers of survived trees

Dbh class (cm)	Block 1	Block 2	Block 3	Block 4
≥ 15 - 30	286	314	315	385
≥ 30 - 45	146	131	152	117
≥ 45 - 60	33	20	65	70
≥ 60 - 75	2	2	5	9
≥ 75	0	1	1	1
Total	467	468	538	582

Results of trees that survived undamaged and with various degrees of damage to the crowns, stems and roots in the harvesting blocks are given in Table 3.5. Obviously, for all species, damage to crowns was the major damage in all blocks, generally followed by stems and roots, except for light damage in Blocks 2 and 3 where roots showed the highest damage. Wan Mohd Shukri *et al.* (2000) also reported that crown damage was the main damage followed by stem and root damage in the RIL related study at Jerangau FR, Terengganu. For all species having various degrees of damage, although heavy damage was the highest in Blocks 1, 3 (especially) and 4, it was followed by light damage in Block 3 and 4 and medium damage in Block 1. In Block 2, however, light damage was the highest, followed by heavy damage. However, the total number of residual trees with damage was relatively low as compared with those trees that were undamaged.

Table 3.5 Numbers of trees that survived undamaged and with various degrees of damage to the crowns, stems and roots (≥15 cm dbh)

Block	Type of damage*	Undamaged	Light damage	Medium damage	Heavy damage
Block 1	Crown	318	25	58	66
	Stem	380	28	33	26
	Root	435	12	8	12
Block 2	Crown	315	47	43	63
	Stem	372	45	26	25
	Root	397	51	7	13
Block 3	Crown	427	18	21	72
	Stem	437	22	14	65
	Root	451	37	10	40
Block 4	Crown	460	30	22	70
	Stem	524	21	16	21
	Root	574	1	1	6

Note: *number of trees may overlap for crowns, stems and roots.

There were only two causes of damage monitored in this study: felling and extraction. Felling damage was caused during the tree felling activity, while extraction damage was caused when the logs were being pulled along the 'jalan tarik Rimbaka' (JTR) by the RTH. It was noted that the fellers had adopted directional felling of trees in all harvesting blocks. Table 3.6 shows the causes of damage to the crowns, stems and roots in each harvesting block. Generally, extraction registered a minor contribution to the damage cause, except for Block 3 that gave 21.3%. In fact, extraction caused only about 1.6% damage to the residual trees in Block 4.

Table 3.6 Causes of damage to crowns, stems and roots based on survived trees in different blocks (≥ 15 cm dbh)

Damage type	Block 1		Block 2		Block 3		Block 4	
	Felling	Extraction	Felling	Extraction	Felling	Extraction	Felling	Extraction
Crown	141	8	141	12	98	13	121	1
Stem	81	6	87	9	72	29	57	1
Root	29	3	61	10	66	22	7	1
Total	251 (93.4%)	17 (6.6%)	289 (90.3%)	31 (9.7%)	236 (78.7%)	64 (21.3%)	185 (98.4%)	3 (1.6%)

Even though directional felling was applied during the felling activity, damage due to felling was unavoidable as the PSF is relatively dense compared with the dry inland forests (Khali Aziz *et al.* 2009). Therefore, the felling activity would cause some damage or even mortality to some of the residual trees. Fortunately, the PSF being on flat and soft land, damage to the residual trees was minimized as the felled trees caused damage on the spot. It has been reported that on steep terrain in hill forests significant damage to residual trees was caused during the felling operation as the felled trees might slipped down the terrain (Kamaruzaman 1996).

In the harvesting operation, Block 3, which recorded the highest damage due to extraction at about 21.3% was harvested first followed by Blocks 4, 2 and 1 successively. Block 3 and half of Block 4 were harvested in late 2006, but temporarily stopped until February 2007 due to flooding during the monsoon season. The study area was completely harvested by May 2007. The damage assessment survey was done during the whole of July 2007 on all the harvesting blocks. Block 3 being the first block to be harvested suffered the highest damage during the extraction activity as the Rimbaka operators were still familiarizing their skills in the operation. This is in line with the general finding by Wan Razali (1993) who reported that less experienced operators could create more damage. Most of the dead trees were caused by the felling activity, recording 88.8%, 82.3%, 66.7% and 88.3% in Blocks 1, 2, 3 and 4 respectively (Table 3.7).

The damage from extraction is much related to the number of extraction lines. More extraction lines will cause more damage to the residual trees. Therefore the extraction lines have to be reduced. It could be reduced by directing several felled trees to the pre-determined directions. The determination of pre-determined direction for the extraction should be done during the preparation of harvesting plan as described by Elias and Khali Aziz (2008).

Table 3.7 Causes of tree mortality in different blocks (≥ 15 cm dbh)

Cause	Block 1	Block 2	Block 3	Block 4
Felling	71 (88.8%)	65 (82.3%)	70 (66.7%)	68 (88.3%)
Extraction	9 (11.2%)	14 (17.7%)	35 (33.3%)	9 (11.7%)
Total	80 (100.0%)	79 (100.0%)	105 (100.0%)	77 (100.0%)

3.3.4 Comparison of Log Production and Damage on Residual Trees

The production of logs and number of trees felled for Block 1 were 4.4 m^3 ha^{-1} and 8.4 stems ha^{-1} more than for Block 2 (Table 3.2). The only difference between both blocks was the cutting limit of Group 1 species, in which Block 1 had a cutting limit less by 5 cm. Nonetheless, the percentages of dead, damaged and undamaged trees in both blocks were fairly similar.
The average percentages of the dead and undamaged trees for all four blocks were 14.3 and 63.5% respectively. In terms of damaged trees, the average percentage of trees that indicated heavy damage was about 11.4% (Table 3.3). These trees were expected to die due to their heavy damage condition. The average percentage of trees having combined medium and light damage was 10.8% (Table 3.3). These trees were expected to survive as the residual trees since their damage was considered acceptable for the trees to grow. Therefore, the total loss of trees $\geq$15 cm dbh in the areas was a combination of dead and heavily damaged trees at 25.7%. However, it has to be noted that four sets of cutting limits representing low to high cutting limits were used in this study.

The log production in Block 4 was fairly high at about 51.2 m^3 ha^{-1} even though only about 18.7 stems ha^{-1} of trees were felled. Their undamaged trees at 69.8% were the highest and dead trees at 11.7% were the lowest among the all four blocks. Block 3 produced 80.3 m^3 ha^{-1} of logs at 34.0 stems ha^{-1} of trees felled. The percentages of undamaged, dead and damaged trees at 66.4, 16.3 and 17.3% respectively in Block 3 were relatively not too far different from those in Block 4, though Block 3 had more trees felled by 15.3 stems ha^{-1}.

Even though Block 4 had the lowest percentage of dead trees, the damaged tree percentage was higher than for Block 3; moreover the log production of Block 4 was far lower. The log production of 80.3 m^3 ha^{-1} in Block 3 might be considered as economically feasible as an economic cut of dry inland forest is set at 80 m^3 ha^{-1} for primary forest (Salleh *et al.* 2008). It might be the same case of economic cut for the PSF. Lowering the cutting limit, especially for those species in Group 3, to 40 cm dbh as in Blocks 1 and 2 had resulted in more gap openings and damage to the residual trees. Therefore, it can be said that the cutting limits of Block 3 had given the most appropriate log production and relatively acceptable harvesting impact on the residual trees.

3.3.5 Comparison With Another Similar Study

Only the study by Zulkifli (2005) is suitable for comparison of these results due to the similarity of the RIL system and type of data collected. He also investigated the impacts of harvesting using Rimbaka in PSF at Pekan FR. Zulkifli (2005) recorded an average of 253.3 stems ha^{-1} of trees $\geq$15 cm dbh; about 8.8 stems ha^{-1} were felled with log production of 43.6 m^3 ha^{-1}. The total percentage of damaged and dead residual trees was about 17.5%. Out of all residual trees surveyed, about 82.5% of the trees were undamaged.

The number of stems felled in the current study at 36.9 stems ha^{-1} was about four times that of Zulkifli (2005) at about 8.8 stems ha^{-1}. However, the average log production of the current study at 87.0 m^3 ha^{-1} was only about double that of Zulkifli (2005). It has to be noted that Blocks 1 and 2 in this current study each produced more than 100.0 m^3 ha^{-1}. In addition, Zulkifli (2005) only harvested trees with $\geq$ 60.0 cm dbh (Chong & Latifi 2003); therefore his volume was higher, even though the number of trees felled was lower.

It was also found that, generally, results of lightly and medium damaged trees, heavily damaged trees and dead trees in the current study were also about double as compared with the results of Zulkifli (2005). In total, the percentage of damaged and dead trees in the current study was about 36.5%, while the study by Zulkifli (2005) reported about 17.5%. Meanwhile, undamaged trees in this current study was lower at about 63.5% compared with about 82.5% as reported by Zulkifli (2005). Highly selective harvesting by adopting high cutting limits and selection of only preferred species to be harvested (Chong & Latifi 2003) in the study of Zulkifli (2005) were the main reasons for the low damage and high undamaged residual trees.

3.4 CONCLUSIONS

Major damage to the forest stands harvested using the RIL system is caused by the construction of forest roads (secondary road) and JTR (Chong & Latifi 2003, Zulkifli 2005). It is because total clear cutting of trees had to be done in those areas for movement of the harvesting machinery. Nevertheless, road and JTR constructions at the PSF under the RIL using RTH were relatively very small in area cleared as they constituted only about 0.6% (total of 0.6 ha) and 2.0% (total of 2.0 ha) respectively of the 100 ha of harvesting area (Elias & Khali Aziz 2008, Zulkifli 2005). However, field observations in the current study found that portions of JTRs exceeded their prescribed widths of 5 m (Elias & Khali Aziz 2008), resulting in more gap openings in forest areas and damage to the forest stands. Therefore, even with the implementation of RIL in PSF, regular monitoring, checking and enforcement should be conducted to ensure close compliance with the prescribed guidelines.

The RIL in this study recorded considerably low damage impacts on the residual trees, though the damage was higher than in another study by Zulkifli (2005) using a similar system. Based on this study, the overall damaged and dead residual trees were about 36.5%. The dead trees due to the harvesting operation only constituted about 14.2%. In fact, the residual trees that received various degrees of damage or died were mainly due to the felling activity, which is generally common in all harvesting operations. It was found that log extraction, the main part of the RIL, only contributed a small portion to the overall damage or tree mortality as compared with the felling activity. It is clear that the implementation of RIL in PSF helps to minimize damage to the residual trees. This study has shown that RIL had successfully produced relatively low damage and mortality to the residual trees and therefore should be continued and encouraged in the harvesting of the PSF.

CHAPTER FOUR

DETERMINATION OF OPTIMUM HARVESTING AND CUTTING CYCLE FOR PEAT SWAMP FOREST

By

Ismail Harun, Harfendy Osman & Ismail Parlan

4.1 INTRODUCTION

Accurate estimation of population dynamics, growing stock, cutting cycles and allowable harvest which are biologically sustainable is important in achieving sustainable forest management in production peat swamp forests (PSF). Currently, the PSF in Peninsular Malaysia is managed under a modified Selective Management System (SMS), which was basically a system designed for the management of the dry inland forests.

As the PSF is a unique forest type with silvicultural characteristics that are rather different from those of the dry inland forests, it is hoped that through this study, suitable silvicultural and management practices could be formulated so that the PSF could be managed in a sustainable manner.

4.2 MATERIALS AND METHODS

The study was undertaken in three major parts as follows:

4.2.1 Part 1: Analysis of Permanent Sample Plot

In early 2008, a study was undertaken to decollate and reanalyze growth and yield data from a permanent sample plot established 1998 under the Malaysian-DANCED project (Mohd Hizamri 2006). The plot was located in Compartment 99, Pekan Forest Reserve (FR) (Figure 4.1). Measurements of the plot were done in 1998, 1999, 2000, 2003 and 2006. The design of the plot was a one-ha plot per treatment and was replicated twice. The treatments given are as indicated in Table 4.1. The amounts of timber removed from the original forest are as shown in Figure 4.2.

Analysis was undertaken to estimate diameter growth or increment, annual mortality rate and annual ingrowth for different diameter classes and species group [i.e. Dipterocarps meranti (DM), Dipterocarps non-meranti (DNM), Non-dipterocarps light hardwoods (NDLHW), Non-dipterocarps medium hardwoods (NDMHW), Non-dipterocarps heavy hardwoods (NDHHW), Non-dipterocarps misc. (NDMICS), Ramin (RAMIN) and Bintangor (BN)]. For the purpose of the study, calculation was done for all trees equal and greater than 15 cm dbh.

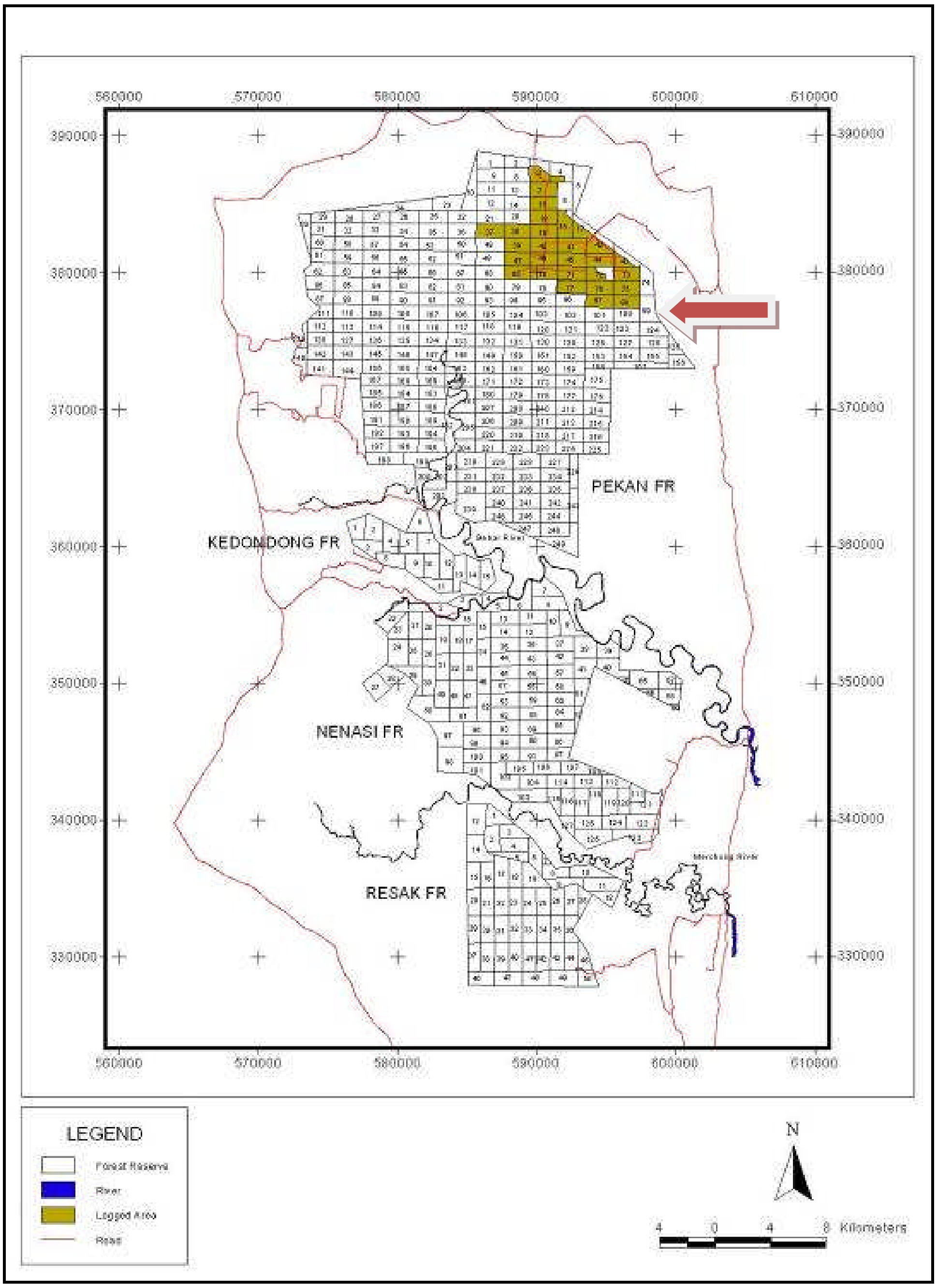


Figure 4.1 Location of the study area in Compartment 99, Pekan FR, Pahang

Table 4.1 Plot treatments in Compartment 99, Pekan FR

Treatment	Abbreviation
High cutting intensity (cutting all trees 30 cm dbh and larger) – 36%	T1
Medium cutting intensity (cutting all trees 45 cm dbh and larger) – 20%	T2
Low cutting intensity (cutting all trees 60 cm dbh and larger) – 29%	T3
Medium cutting intensity with selective cutting by diameter classes (30 cm dbh and larger) – 21%	T4
Control (minimal cutting) – 9.5%	T5

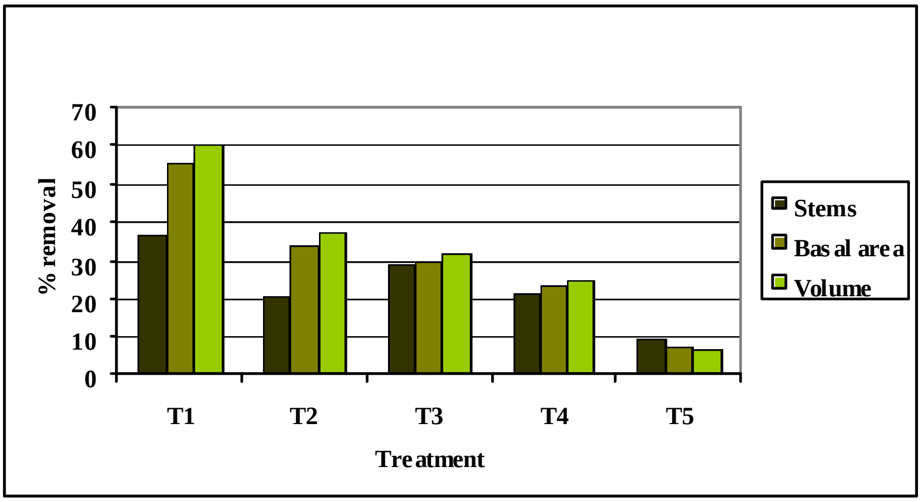


Figure 4.2 Percentages percent of removal from the plots

4.2.2 Part 2: Development of Yield Projection Model

This part of the study was undertaken to develop a stand projection model using growth parameters obtained in Part 1. The model was developed based on MYRLIN which was developed by Alder *et al.* (2002). Some modifications were made to MYRLIN on the diameter increment and species grouping, where species were grouped into the eight species groups of DM, DNM, NDLHW, NDMHW, NDHHW, NDMICS, RAMIN and BN.

In 2007, the modified model called Growth and Yield Model for Mixed Tropical Forest (GYMMTF) was developed by Ismail (2007) who later developed Growth and Yield Model for Tropical Peat Swamp Forest (GYMTPSF) in 2008. The model was written using MS Office Access with the ability to save output data into MS Excel. The structure of the model consisted of three main modules, i.e. Database preparation, Simulation and Outputs. The outputs then were used in the later part of the study.

4.2.3 Part 3: Determination of Optimal Cutting Cycles

The method used in this study was by calculating mean and current annual increments (MAI & CAI). The optimum cutting cycle was determined when MAI was equal to CAI by using data from FRIM's study site at Compartment 77, Pekan FR (Ismail *et al.* 2005, and refer to Chapter 1). The study area of 100 ha was divided to four blocks assigned with different cutting limits (Table 4.2).

Table 4.2 Cutting limits for species group in each harvesting block at Compartment 77, Pekan FR

Block	**Cutting limits (dbh)**	**Description**
	Group1 – Group 2 – Group 3	
1	50 – 45 – 40	Low cutting limits
2	55 – 45 – 40	Medium cutting limits
3	60 – 50 – 45	Medium cutting limits
4	65 – 55 – 50	High cutting limits

Group 1 = *G. bancanus* and dipterocarps only
Group 2 = *Callophyllum* spp. only
Group 3 = other species

4.3 RESULTS AND DISCUSSION

4.3.1 Diameter Increment

Results indicated that the overall diameter growth of trees in PSF including *Gonystylus bancanus* is slower than that of other inland species. *Gonystylus bancanus* recorded the diameter growth of 0.28 to 0.51 cm yr^{-1}, depending on the total basal area (TBA). The average mortality and ingrowth was recorded at about 2% per year. The diameter increments are shown in Table 4.3.

Table 4.3 Diameter increments of all species in PSF (cm yr^{-1})

	Count	Minimum	Maximum	Mean	Standard error of mean	Standard deviation
1	270	.000	3.500	.574	.032	.518
2	366	.000	3.588	.517	.024	.451
3	357	.000	6.300	.596	.028	.532
4	355	.000	6.413	.626	.037	.693
5	456	.000	3.750	.499	.022	.470

For the purpose of modelling, series of diameter increment functions were developed as shown in Table 4.4. The diameter increment function for *G. bancanus* over total basal area is shown in Figure 4.3. The species recorded average diameter increments of 0.28 to 0.51 cm yr^{-1}.

Table 4.4 Diameter increment functions for all species group in PSF

Species Group	**Diameter increment functions**
1. Dipterocarps Meranti (DM)	$D_i = \exp^{(-0.15359-0.011392*TBA)} - 0.2$
2. Dipterocarps Non-meranti (DNM)	$D_i = \exp^{(-0.191158-.0112268*TBA)} - 0.2$
3. Non-Dipterocarps Light Hardwoods (NDLHW)	$D_i = \exp^{(-0.27367-0.0135317*TBA)} - 0.2$
4. Non-Dipterocarps Medium Hardwoods (NDMHW)	$D_i = \exp^{(-0.107701-0.0150806*TBA)} - 0.2$
5. Non-Dipterocarps Heavy Hardwoods (NDHHW)	$D_i = \exp^{(-0.03232-0.0204071*TBA)} - 0.2$
6. Non-Dipterocarps Miscl. (NDMICS)	$D_i = \exp^{(-0.087761-0.0112406*TBA)} - 0.2$
7. *G. bancanus* (RAMIN)	$D_i = \exp^{(-0.26537-0.0147317*TBA)} - 0.2$
8. Bintangor (BN)	$D_i = \exp^{(-0.25867-0.0147521*TBA)} - 0.2$

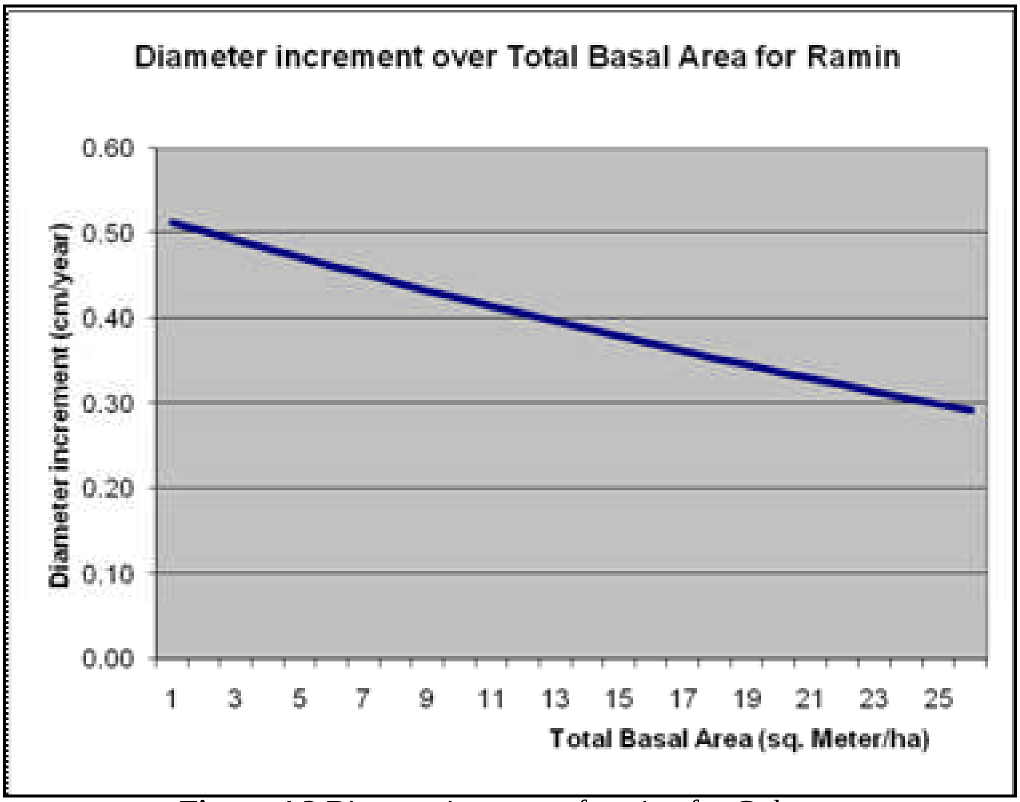


Figure 4.3 Diameter increment function for *G. bancanus*

4.3.2 Mean Annual Volume Growth

Mean annual volume increment for *G. bancanus* was recorded at an average of 0.215 $m^3ha^{-1}yr^{-1}$ out of the total MAI of 1.8 $m^3ha^{-1}yr^{-1}$ for all species equal and greater than 15 cm (Table 4.5). The result also indicate that medium and high cutting limits produce better future growth responses, especially for Block 3: 60/50/45 and Block 4: 65/55/50 (Table 4.2).

Table 4.5 Mean annual volume increments for all species and *G. bancanus* in PSF

Mean Annual Increment	Block 1	Block 2	Block 3	Block 4
All species ($m^3ha^{-1}yr^{-1}$)	1.84	1.88	1.75	1.80
G. bancanus only ($m^3ha^{-1}yr^{-1}$)	0.212	0.199	0.234	0.213

4.3.3 Optimum Cutting Cycle and Initial Growing Stock

Using the GYMTPSF, the projected volume using all residual stands indicates that option 4 (Block 4) produced the highest volume growth response as compared with the others (Table 4.6 and Figure 4.4). The projections were done for a period of 120 years. Projections for total trees and volume for *G. bancanus* are shown in Figures 4.5 and 4.6.

Table 4.6 Volume projections after felling by block

Year	Block 1 (m^3)	Block 2 (m^3)	Block 3 (m^3)	Block 4 (m^3)
0	73.97	68.92	102.80	107.49
5	84.14	79.63	114.22	116.20
10	94.17	89.39	120.35	124.95
15	104.88	100.15	131.56	138.29
20	116.11	111.17	142.64	150.88
25	127.46	122.26	153.72	162.93
30	138.58	133.16	164.57	174.30
35	149.26	143.68	174.90	184.83
40	159.41	153.69	184.53	194.44
45	168.93	163.11	193.36	203.13
50	177.78	171.90	201.34	210.91
55	185.94	180.07	208.51	217.86
60	193.41	187.61	214.89	224.04
65	200.21	194.56	220.56	229.53
70	206.37	200.93	225.56	234.41
75	211.92	206.75	229.98	238.74
80	216.93	212.06	233.87	242.59
85	221.44	216.88	237.30	246.01
90	225.48	221.25	240.32	249.05
95	229.09	225.20	242.97	251.76
100	232.32	228.76	245.30	254.16
105	235.20	231.96	247.35	256.29
110	237.75	234.82	249.15	258.17
115	240.01	237.37	250.71	259.82
120	241.99	239.63	252.08	261.28

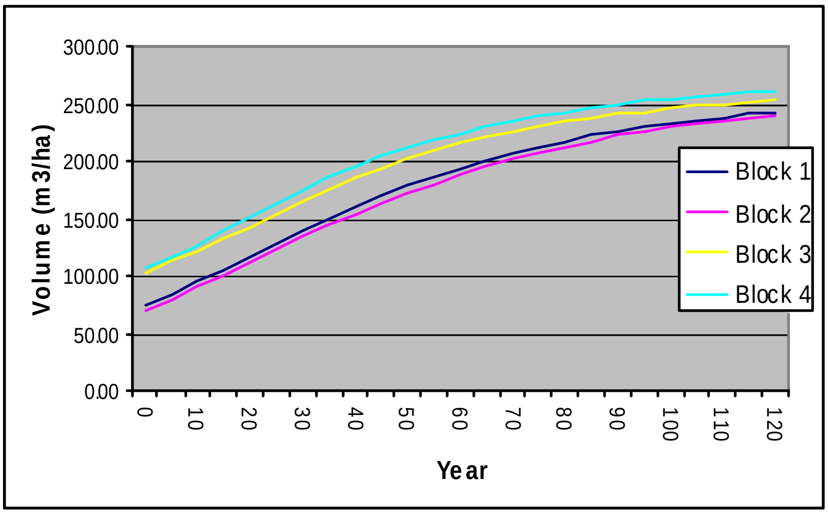


Figure 4.4 Volume (m^3) projections after felling

Figure 4.5 Projected numbers of *G. bancanus* stands (trees ha^{-1}) for 120 years

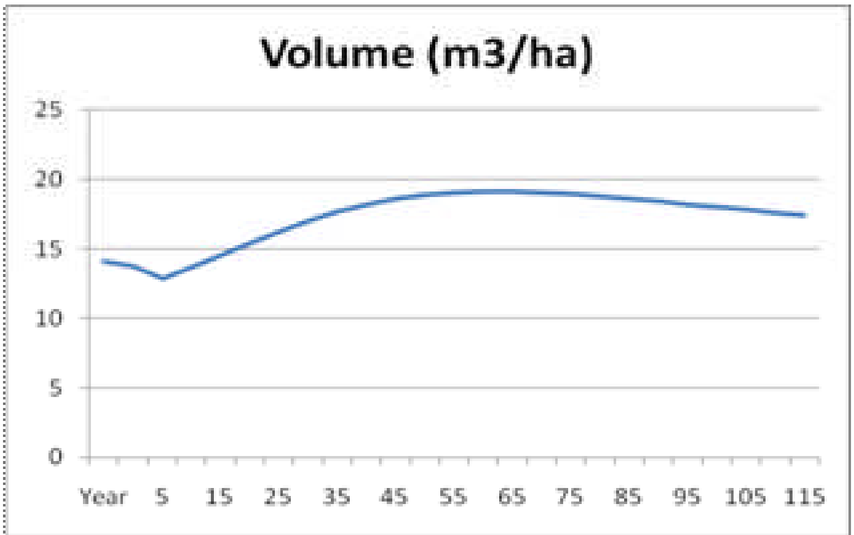


Figure 4.6 Projected volumes (m^3ha^{-1}) of *G. bancanus* trees for 120 years

The results also indicates that the optimum cutting cycle for the whole stand is estimated at about 40 years with a projected volume increment of about 1.8 m^3ha^{-1} year as given in Table 4.7. The initial growing stock after felling that has to be retained in the forest is 100 m^3ha^{-1} (dbh $\geq$15 cm) for all species. If the stand is to be managed at a cutting cycle of 40 years, the maximum gross harvestable volume for the whole stand is projected to be 72 m^3ha^{-1}, of which 8.9 m^3ha^{-1} is of *G. bancanus*.

Table 4.7 Mean volume increments and optimum cutting cycles for PSF in Pekan FR

Parameter	Blok 1	Blok 2	Blok 3	Blok 4
Mean volume increment ($m^3ha^{-1}yr^{-1}$)	1.84	1.88	1.75	1.80
Optimum cutting cycle (year)	35-40	35-40	35-40	35-40

4.4 CONCLUSIONS

Overall trees in PSF grow at slower rates (average diameter growth of 0.2 to 0.6 cm yr^{-1}) than those in inland forest. The study also indicated that medium removal (20–30%) produced better diameter, basal area and volume growths. In this study, a projection model, GYMTPSF, was successfully developed. It is a simple, accurate and user–friendly model. The study also indicated that the volume MAI for the whole stand in PSF is about 1.8 $m^3ha^{-1}yr^{-1}$ for all trees equal and greater than 15 cm dbh. It can be concluded that the medium and high cutting limits produced better future growth response. In management the optimum initial growing stock after felling should be at least 100 m^3ha^{-1} (dbh $\geq$ 15 cm). The optimum cutting cycle is projected at 40 years with a gross harvestable volume at 72 m^3ha^{-1} for all species and 8.9 m^3ha^{-1} for *G. bancanus*.

CHAPTER FIVE

FINANCIAL EVALUATION OF TIMBER HARVESTING IN PEAT SWAMP FOREST

By

Salleh Mat, Ismail Parlan & Ahmad Fauzi Puasa

5.1 INTRODUCTION

Forest harvesting for timber extraction in Peninsular Malaysia has been carried out since the late nineteenth century (Wong 2001). Forest harvesting activities play a main role in socio-economic and rural development. In the forest harvesting practices in Peninsular Malaysia, a forest area would be opened for harvesting as a long-term agreement area (timber complex), short-term agreement area (sawmill scheme), on tender or others.

Long-term forest concession contract/agreement has been preferred in order to facilitate exploitation sustainability (Barbone & Zalduendo 2000), security or sustainability of raw material supply as a major incentive for local wood processing (Schmithiisen 1976), while in short-term forest concession, the logging and sawmilling industry cannot invest in modern and environmentally friendly equipment due to the uncertainty of operation in the following years (Havelund & Saharuddin 1999).

The costs of forest harvesting vary as recorded in previous studies. They depend on the harvesting activities selected in the analysis, for instance, supervised harvesting or unsupervised harvesting, and types of forest harvesting method such as ground-based harvesting using crawler tractor and forest harvesting using skyline system and so forth. Ismail Adnan (1990, 1991) stated that the cost of log skidding using "winch mounted sled" in the PSF was RM15.48 m^{-3}. Muhammad Farid and Shamsudin (1992) reported that the operating cost of skyline cable system was RM8.65 m^{-3}. The above studies recorded the costs of skidding operation only but the overall costs of forest harvesting were not calculated.

There have been no study results on profit from timber harvesting in PSF in Peninsular Malaysia. However, as a comparison, the profit from timber harvesting in hill forest can be used. The profit generated from timber harvesting in hill forest by concessionaires varies depending on the timber species produced and log prices. Verissimo *et al.* (1995) showed that the profit gained from conventional timber harvesting was USD800,000.00 (RM2.02 million)[1] per year. Another study showed that the annual profit of timber harvesting in sustainable forest management (SFM) was estimated at USD217,000.00 (RM551,180.00) or USD900.00 ha^{-1} (RM2,286.00 ha^{-1})[2] (Verissimo *et al.* 1992).

The viability of forest harvesting practices could be determined by the net present value (NPV) of timber extraction, viz. using the benefit and cost analysis (BCA) approach. In some studies, BCA has been used to compare the NPV or profitability of timber harvesting in SFM with that in unsustainable forest management. For instance, a study conducted by Barreto *et al.* (1998) showed that the NPV of timber extraction in hill forest with forest management (planned logging operation) was 38 to 45% higher than that without management (unplanned logging operation).

To date, a specific system of forest management for PSF in Peninsular Malaysia has not been produced. Therefore, the study as described in previous chapters was conducted to determine and develop a suitable cutting regime and the results of the study would be used as a system for the management of PSF for timber production. A financial analysis was carried out in order to determine the cutting limits/regimes suitable for timber harvesting in terms of financial return. This would assist the forest manager to control costs of forest management/logging and to compare the viability of timber harvesting with SFM (certified timber produced) and without SFM (uncertified timber produced).

5.2 OBJECTIVE

Generally the objective of the financial study was to determine the viability of timber harvesting in PSF with SFM, specifically:

- to estimate the costs and benefits and viability of timber harvesting in PSF;
- to conduct a sensitivity analysis of timber harvesting in PSF.

5.3 MATERIALS AND METHODS

5.3.1 Study Site

The study was carried out in Compartment 77, Pekan Forest Reserve (FR), Pahang as described in Chapter 1.

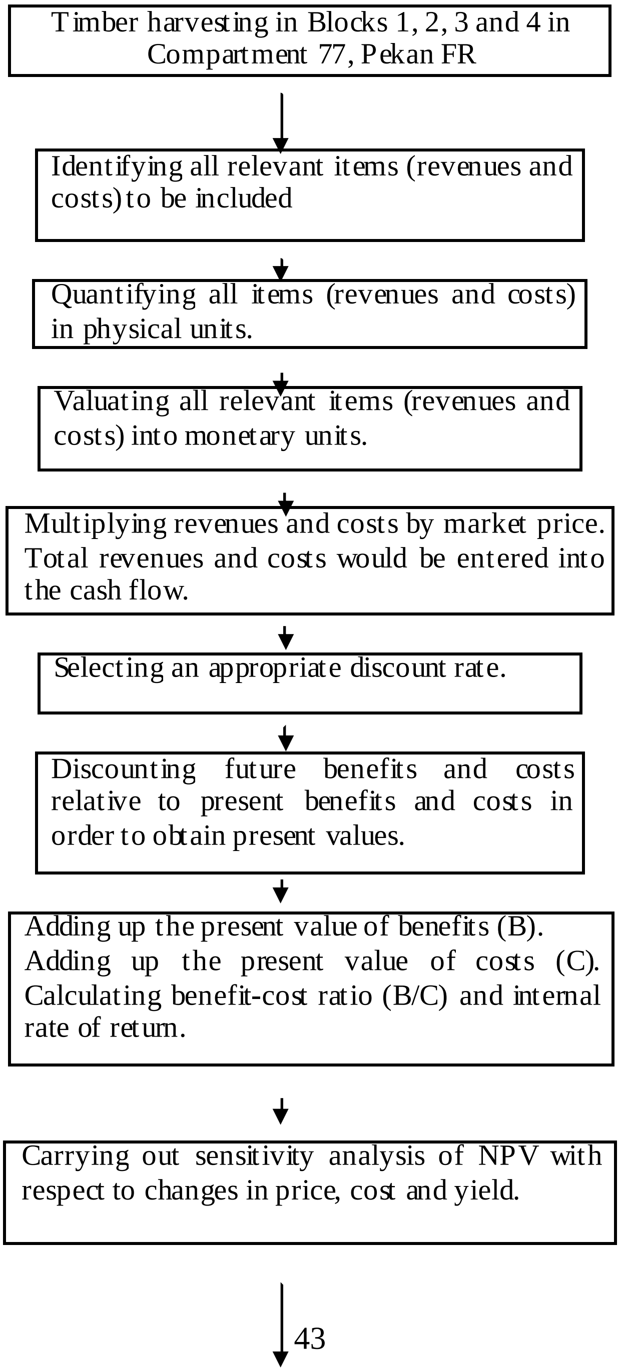
[1] 1 USD = RM 2.53
[2] 1 USD = RM 2.54

5.3.2 Framework of the Financial Evaluation

The framework of the financial evaluation is shown in Figure 5.1. The benefits and costs derived with SFM from the long-term forest concession were calculated. Then the incremental net benefit was obtained.

The ten percent (10%) discount rate was selected and used in the cash flow with SFM. The discount rate (interest rate) was based on basic loan rate (BLR) or existing interest rate in the market as provided by Bank Negara.

The normal cutting cycle of timber harvesting is 30 to 60 years. In this study, the 35-yr cutting cycle was selected and the cash flow was developed for 35 yr only.



Recommending the value of NPV with SFM either lower or higher than without SFM.

Figure 5.1 Framework of the financial evaluation

5.3.3 Identifying Costs and Benefits

Data on the primary timber harvesting costs and log production from study area were directly collected either from the logging contractor (Upayapadu Sdn. Bhd.) or at the study site and summarized into a standard form survey. Standard forms for the survey to record all data of timber harvesting activities are given in Appendices 5.1 and 5.2. A constraint of this study was in obtaining data on the hire rates for the logging operations such as for operating chain-saw, Rimbaka timber harvester (RTH), traxcavator (locally called *itik*), lorry and others, the time consumed and budget. All costs for each of the timber harvesting activities were summarized and calculated on per hectare (RM ha^{-1}) and per cubic meter (RM m^{-3}) basis.

5.3.4 Quantifying and Valuing Costs and Benefits

The actual log production from each block was used in the analysis. Table 5.1 shows the basic information on the study area.

Table 5.1 Basic information on the study area

Item	**Total volume (m^3)**	**Volume per ha (m^3 ha^{-1})**
Log production in Block 1 (25 ha)	2,763.18	110.53
Log production in Block 2 (25 ha)	2,653.52	106.14
Log production in Block 3 (25 ha)	2,125.42	85.02
Log production in Block 4 (25 ha)	1,279.46	51.18
Total log production (100 ha)	8,821.58	88.22

In the cash flow, timber harvesting was assumed to be carried out one hectare per year. Log price was multiplied by the timber production in each year to get the total benefit, while the cost of timber harvesting per hectare according to activity was multiplied by the annual areas in each year to get the total cost.

i) Log prices

The ex-betau log prices used in this financial analysis were provided by Amanah Saham Pahang (ASPA). An average of 12 months log prices in 2006 was calculated.

ii) Investment criteria

In this study, the viability of timber harvesting in PSF from reduced impact logging (RIL) system was evaluated using the BCA as elaborated by World Bank (2001). The investment criteria used in the analysis were:

- net present value (NPV);
- internal rate of return (IRR);
- benefit and cost ratio (B/C).

The decision rule is that all of the project is feasible when the value of NPV is greater than 0, IRR value greater than the cost of capital (i.e. discount rate used) and B/C ratio greater than 1. The formulas to calculate the values of NPV, IRR and B/C are as follows:

a) Formula of NPV

$$NPV = \sum_{t=1}^{35} \frac{B_t - C_t}{(1 + r)^t}$$

Where,

B_t	= total value of benefits for a period of years, t
C_t	= total value of costs for a period of years, t
r	= discount rate
$1/(1+r)^t$	= discount factor
t	= year 1 to year 35

b) Formula of IRR

$$IRR = \sum_{t=1}^{35} \frac{B_t - C_t}{(1 + r)^t} = 0$$

c) Formula of B/C

$$B/C\ ratio = \sum_{t=1}^{35} \frac{B_t}{(1 + r)^t}$$

iii) Sensitivity analysis

Sensitivity analysis was carried out in this study in order to obtain the NPV and benefit-cost ratio due to changes in cost, price and yield.

The formula of sensitivity analysis = $$\sum_{t=1}^{35} \frac{C_t}{(1 + r)^t}$$

iv) Criteria used in the cash flow

The criteria used in financial cash flow are as presented in Table 5.2.

Table 5.2 Criteria used in calculating financial cash flow

No.	**Item**	**Financial cash flow**
1.	Area	1 ha per year
2.	Production of logs	Log production was based on actual production in each block. Yield factor: 1 Conversion factor: 1
3.	Log price	Log price at matau was used. Price factor: 0.80 Conversion factor: 1
4.	Cost of timber harvesting	Actual/primary cost. Cost factor: 1 Conversion factor: 1
5.	Labour	Skilled labour
6.	Discount rate	Used 10%

5.4 RESULTS AND DISCUSSION

5.4.1 Costs of Timber Harvesting

Table 5.3 presents the costs of timber harvesting in the PSF. The costs were divided into two main categories, namely administration costs and logging operation costs. Administration costs consisted of premium only. The total cost of administration was RM10,518.84 ha^{-1} (RM119.24 m^{-3}) or 46.44% of the overall cost.

Logging operation costs were divided into sub-costs, namely cost of Pre-F and cost of felling. The cost of pre-felling comprised those of Pre-F inventory, compartment boundary demarcation and tree marking. The highest cost component in pre-felling was Pre-F inventory (RM175.00 ha^{-1} or RM3.97 m^{-3}), followed by tree marking (RM104.31 ha^{-1} or RM1.14 m^{-3}). The total cost of Pre-F was RM313.06 ha^{-1} or RM5.54 m^{-3} or 2.16% of the overall cost. The main road, feeder roads and skid trails were constructed using an excavator. The excavator was used to reduce damage to standing trees. The cost of felling consisted of those of felling and bucking, log haulage, log skidding, log transportation, base camp, matau construction, road construction and others. The highest cost component in felling was other costs (RM6,358.18 ha^{-1} or RM72.08 m^{-3}), followed by log skidding (RM2,425.93 ha^{-1} or RM27.50 m^{-3}) and road construction (RM1 036.36 ha^{-1} or RM11.75 m^{-3}). The total cost of felling was RM11,644.80 ha^{-1} (RM132.01 m^{-3}) or 51.42% of the overall cost.

It was found that the total cost of timber harvesting in PSF was RM22 476.70 ha^{-1} (RM256.79 m^{-3}). The highest cost was from felling (51.42%), while the lowest cost was from Pre-F (2.16%).

Table 5.3 Costs of timber harvesting per tonne (RM t^{-1}), per cubic meter (RM m^{-3}) and per hectare (RM ha^{-1})

No.	Items	%	RM t^{-1}	RM m^{-3}	RM ha^{-1}
(A)	Administration cost:				
1	Premium	46.44	216.79	119.24	10,518.84
	Subtotal	46.44	216.79	119.24	10,518.84
(B)	Logging operation cost:				
	Pre-felling				
2	Pre felling inventory	1.55	7.21	3.97	175.00
3	Boundary demarcation	0.17	0.78	0.43	37.75
4	Tree marking	0.44	2.07	1.14	100.31
	Subtotal	2.16	10.06	5.54	313.06
	Felling				
5	Felling and bucking	1.50	7.00	3.85	339.63
6	Log haulage (Rimbaka)	3.43	16.00	8.80	776.33
7	Log skidding (traxcavator /*itik*)	10.71	50.00	27.50	2,425.93
8	Log transportation (lorry)	1.07	5.00	2.75	242.59
9	Base camp/kongsi construction	1.03	4.80	2.64	232.89
10	Matau construction	1.03	4.80	2.64	232.89

11	Road construction	4.58	21.36	11.75	1,036.36
12	Other cost	28.07	131.04	72.08	6,358.18
	Subtotal	51.42	240.00	132.01	11,644.80
	Total	100.00	466.85	256.79	22,476.70

The costs of timber harvesting in PSF increased owing to time consumed, increasing prices of petrol and other goods in the global market, the number of foresters involved in supervision and monitoring and complying with new harvesting regimes.

5.4.2 Benefit of Timber Harvesting

The results of the BCA are presented in Table 5.4. The analysis considered the timber cycle of 35 years. The production values of timber extraction in Block 1 to Block 4 are 110.53 m^3 ha^{-1}, 106.14 m^3 ha^{-1}, 85.02 m^3 ha^{-1} and 51.18 m^3 ha^{-1} respectively. The results show that timber harvesting for the blocks generated net revenues (before discounting) of RM41,363.14 ha^{-1} (RM1,181.80 ha^{-1} yr^{-1}) to RM1,024,935.93 ha^{-1} (RM29,283.88 ha^{-1} yr^{-1}). The average log prices used were RM639.38 m^{-3} (Block 1), RM639.38 m^{-3} (Block 2), RM649.16 m^{-3} (Block 3) and RM652.86 m^{-3} (Block 4).

Table 5.4 Net benefits of timber harvesting in four blocks

Block	**Cutting cycle (yr)**	**IRR (%)**	**Discounting B/C ****	**NPV at 10% (RM ha^{-1})**	**NPV at 10% (RM $ha^{-1}yr^{-1}$)**
Block 1	35	72.62	2.06	230,095.90	6,574.17
Block 2	35	68.13	1.98	212,351.64	6,067.19
Block 3	35	46.16	1.61	132,157.20	3,775.92
Block 4	35	-2.75	0.97	-5,622.43	-160.64

*Note: ** denotes discounting C and B at r =10%*

The viability of timber harvesting of all blocks is evaluated from outcomes in the IRR, B/C and the NPV. From Table 5.4, the NPV and IRR of the blocks respectively fall between –RM160.64 ha^{-1} y^{-1} and RM6 574.17 ha^{-1} y^{-1}, and between -2.75% and 72.62% respectively. Based on NPV, IRR and B/C criteria, the best performance is shown by Block 1.

The sensitivity analysis was carried out and the results are shown in Table 5.5. If costs and log production are constant, the lowest prices for timber harvesting to be viable are RM319.69 m^{-3} (Block 1), RM332.48 m^{-3} (Block 2), RM408.97 m^{-3} (Block 3) and RM678.97 m^{-3} (Block 4). If cost and price are constant, the lowest production was in the range of 53.23 to 55.26 m^3 ha^{-1}. If price and log production are constant, the highest costs of timber harvesting are in the range of RM246.50 to RM796.00 m^{-3}.

Table 5.5 Results of sensitivity analysis

Scenario	Block 1	Block 2	Block 3	Block 4
If cost and log production are constant: Lowest price (RM m^{-3})	319.69	332.48	408.97	678.97
If cost and price are constant: Lowest production (m^3 ha^{-1})	55.26	55.19	53.56	53.23
If price and log production are constant: Highest cost (RM m^{-3})	796.00	744.65	408.27	246.50

5.5 CONCLUSIONS

The results of timber harvesting in all blocks are influenced by the rotation age, the volume extracted, cost and price of logs. The financial analysis gave positive NPV for timber harvesting in Blocks 1 to 3 but negative value in Block 4. Therefore timber harvesting is viable in Blocks 1, 2 and 3, but not in Block 4. As comparison of NPV values, $NPV_{Block1} > NPV_{Block2} > NPV_{Block3} > NPV_{Block4}$. Timber harvesting shows the best performance in Block 1 which complies with the harvesting regime. Nonetheless, selection of the cutting limits also depends on results from other important aspects such as impact analysis on residual trees and optimum harvest.

Appendix 5.1

COSTS OF FOREST MANAGEMENT BY FORESTRY DEPARTMENT										
State	Pahang					Reporter				
Project	Peat Swamp Project					Date				
Location	Pahang Forestry Department					Forest Type	Peat swamp			
District	Pekan									
Compartment/ Block no.	Compartment boundary measured / cleaning (m)	Pre felling inventory (ha)	Tree marking (ha)	Closing report (ha)	Post-F (ha)	Compartment boundary measured / cleaning (RM)	Pre felling inventory (RM)	Tree marking (RM)	Closing report (RM)	Post-F (RM)

Appendix 5.2

HARVESTING COSTS BY CONTRACTORS			
State	Pahang	Reporter	
Project	Peat Swamp Project	Date	
Location	Pahang Forestry Department	Forest Type	Peat swamp
District	Pekan	Area (ha)	
Compartment/ block no.			

Administration costs	**RM**	**Felling costs**	**RM**
Premium		Feller/ chain-saw operator	
Road construction		Chain-saw assistant	
Base camp construction		Long haulage operator/ RTH	
Matau construction		Long haulage assistant	
Harvesting plan preparation		Log skidding operator/ traxcavator *(itik)*	
Hammer registration		Log transportation/ Lorry	
Worker registration		Crew leader/ "kepala"	
Vehicle/ machinery registration		Cook	
Logs transportation to mill		Betau/ camp clerk	
Maintenance		Loader operator at inside matau	
Royalty		Driver (Hi-lux, pajero)	
Cess		Manager	
Other costs		Camp supervisor	
		Fuel	
		Loader operator at outside matau	
		Office clerk	
Sub total		Sub total	

CHAPTER SIX

PRODUCTIVITY AND TIME STUDY OF REDUCED IMPACT LOGGING IN PEAT SWAMP FOREST

By

Salleh Mat, Ismail Parlan & Ismail Talib

6. 1 INTRODUCTION

A productivity and time study was carried out in March 2007 in Compartment 77, Pekan Forest Reserve (FR), Pahang. The study site is as described in Chapter 1. The conventional method of timber harvesting formerly in PSF was a combination of felling, skidding by boat through a man-made canal and log transportation to a temporary matau.

In the current method of reduced impact logging (RIL), timber harvesting is a combination of felling, log extraction from stump using the Rimbaka timber harvester (RTH), log transportation by transporter machine (traxcavator) to a temporary matau and log transportation by lorry to a permanent matau. This time study was intended to measure the productivity and time of RIL using the RTH in PSF.

6.2 HISTORY OF FOREST HARVESTING IN PEAT SWAMP FOREST AND COSTS INCURRED

Studies on the costs of forest harvesting, especially from PSF in Pahang are lacking. Previous studies only focused on the time and productivity of felling and skidding. In Sabah, log extraction in PSF used extensive manpower, known as *kuda-kuda*. The costs of this operation as recorded by Martyn (1966) were calculated through the rate of price per cubic metre according to species (belian, RM4.24 m^{-3}; selangan, RM4.24 m^{-3}; lighter species, RM1.06 m^{-3}). The total haulage or production recorded was 623.04 m^3 $month^{-1}$. The cost of railway construction was RM563.26 m^{-3}. The total distance recorded was 243.84 m. The costs of felling, crosscutting, hauling and debarking were paid on contract basis that varied between the species.

Tramways or pathways (constructed with poles) were used to transport the logs from the end of the *kuda-kuda* line to a river and the logs were then rafted to the shipping centre. However, according to Yap (1966), the cost of log extraction was high for PSF when compared with low hill forest if the extraction site was deep in the forest with tramlines over 16 km (16,093 m) long. He then introduced a winch machine for hauling logs. By using this machine, the average production of logs per gang was improved by about twice when compared with the average production per gang by manpower. However, no costs were recorded. The study was conducted in Selangor, Peninsular Malaysia.

Time studies conducted by Ismail Adnan (1990, 1991) in Sarawak used a mechanized system of log skidding in the PSF, recognized as "winch mounted sled". This system was an alternative to the traditional system of log skidding using manpower (*kuda-kuda)*. The production cost by the mechanized system was RM15.48 m^{-3}. The production cost was lower than that of the *kuda-kuda* system (average of RM50.00 m^{-3}). However the studies only recorded the cost of skidding operation and the overall cost of forest harvesting was not calculated.

Log extraction in PSF of Sarawak using a skyline system was introduced in 1967 (Wood 1967). The costs of felling and yarding operation were paid on contract basis at RM4.50/Hoppus ton (RM2.50 m^{-3})[1] and RM5.00/Hoppus ton (RM2.78 m^{-3}) respectively. These costs did not include overheads on the yarder, depreciation, fuel and so on. The estimated total costs of the operation were not stated. However, it was admitted that the total cost of the operation was higher than the rate for manual extraction with an average of RM15.00/Hoppus ton (RM8.33 m^{-3}) at the rail side.

Muhammad Farid and Shamsudin (1992) reported that the operating cost of skyline cable system in dry inland forest was RM88.48 hr^{-1} and log production was 71.60 m^3 day^{-1}. This study assumed that operating time was 7 hr per day. Thus, the total logging operation cost calculated was RM8.65 m^{-3}. This total cost was only for logging operation and not indicated as an overall cost of forest harvesting.

Chong and Latifi (2001) cited the cost of forest harvesting in PSF using RTH at about RM3,450.00 ha^{-1}. The harvesting activities were based on RIL complying with the Malaysian Criteria and Indicators (MC&I). The cost calculation was based on activities such as planning of compartments, tree identification and marking, tree mapping, road marking and construction, drainage, permanent sample plot (PSP) establishment, skid trail marking and construction, operating the RTH, tree felling, tree bucking and winching, transport to the log yard, sorting and grading in the log yard, loading of log trucks, road maintenance, management support, selling logs and compartment close-out. Additional costs for licence application, licence fees and royalties were not included. These costs were expected to increase in the following years due to price increases of fuels and others.

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[1] 1 Hoppus ton = 1.8 m^3

6.3 MATERIALS AND METHODS

Data collection was divided into two parts. Part 1 was to record the time into formatted forms using stop-watch for each activity in logging (felling, log haulage, log skidding and log transportation), while in Part 2, formatted questionnaire forms were used in interviewing the logging contractor to get information on costs and other items. Other information such as forest stocking data was also collected.

In felling activity, the chain-saw was used for felling and cross-cutting. Before felling, the operator of the chain-saw (feller) would clear the vegetation around the tree, providing a space for movement and determining the direction of fall for the tree. The machine operator would then fell the tree by applying certain directional felling. After that, the crown was cut off and the stem at the merchantable points; the logs were then ready to be hauled by the RTH to the skid trail. All felling activities were done alone by a chain-saw operator.

In log haulage activity, the RTH was used to haul logs from stumps to the skid trail. The RTH operator was assisted by two assistants. The assistants would pull the cable and choke it to the log. The log then would be pulled by the RTH onto the skid trail.

On the skid trail, a log transporter (traxcavator), or locally called *itik*, was ready to transport the logs to a temporary matau. Log transportation from stump to temporary matau was done by a operator of the *itik*. Before the logs were transported, the operator would tie up four or five logs together at the back of the machine ready to be transported to the temporary matau. At the temporary matau, the logs would be released, and sorted. Long logs would be cross-cut into a specific lengths before being transported by lorry to a permanent matau.

A power-modified lorry was used to transport the logs from the temporary matau to the permanent matau. Only one-operator lorry was involved in this activity. The *itik* was used to load logs onto the lorry. A lorry could be loaded with about 12 to 15 logs. The loaded lorry then carried the logs to the permanent matau. When the lorry arrived at the permanent matau, the logs were released from the lorry for further sorting and were ready for sale or to be transported to mills.

6.4 RESULTS AND DISCUSSION

6.4.1 Felling and Cutting (Chain-Saw)

The chain-saw operator went to the felling site with the *itik*. From Appendix 6.1, the average time recorded to walk from tree to tree was 144 s with a distance of 19.90 m. Then the area around the tree was cleared with the time recorded at 72.79 s. Felling was done using STIHL 070 power chain-saw with 9.14 cm guide bars. An average of 178.82 s was required to fell, 122.45 s to decrown and trim an unbutressed tree before the log was ready to be hauled out. The total delay time was 1,194.00 s which included machine services, smoking, rest and others. The length of log was measured at the temporary matau. The average diameter and length of a log were 58.15 cm and 18.19 m respectively. The average volume was 5.12 m^3 per log.

The elements involved in the productivity of felling were walking from tree to tree (TT), clearing around the tree before felling (SC), felling (FL), cutting/decrowning (CC) and delay (DE). Based on the information in Appendices 6.1 and 6.2, the costs and productivity of felling activity were calculated as follows (Box 6.1):

Box 6.1 Productivity and costs of felling

Productive time/basic time (PT):	TT + SC + FL + CC 144.00 + 72.79 + 178.82 + 122.45 = 518.06 s
Total time (TT):	PT + DE 518.06 + 1,194.00 = 1,712.06 s
Average size of tree (volume):	5.12 m^3
Average walking distance (from tree to tree):	19.90 m
Productivity (basic time):	101.18 s m^{-3}
Productivity (total time):	334.39 s m^{-3}
Cost of machine:	RM 2.67 hr^{-1}
Cost of machine:	RM 0.25 m^{-3} (without operator)
Cost of operator:	RM 3.85 m^{-3}
Total cost of felling and cutting:	RM 4.10 m^{-3}

Based on the above calculations, the productivity of felling and cutting was 10.77 m^3 hr^{-1}, while the cost was RM4.10 m^{-3}.

6.4.2 Log Haulage

The RTH was handled by an operator and helped by assistants. The machine operator would check the engine oil and hydraulic oil before the machine was ready to pull out the logs. Generally, the RTH would only pull out one log at a time.

Two machine assistants would pull a cable from the RTH and choked onto the log. From Appendix 1, the time recorded for this activity was 255.60 s. Then the log was pulled by the RTH to the skid trail. The time recorded for pulling log from stump to skid trail was 90.70 s. The average distance for pulling a log was 81.33 m. At the skid trail, the log would be released from the cable with the time taken of 0.37 s. Then all the logs would be sorted at the roadside of the skid trail. The logs were sorted in 89.17 s. The average length of log was 18.44 m with log volume of 5.27 m^3. The average delay time was 2,916 s which include machine break-down and logs stuck between trees.

The elements involved in the productivity of log haulage were pulling/attaching the cable and tying up the log (AC), pulling out the log from the stump (PL), loosing the cable from the log (LC), sorting the log (SL) and delay (DE). Based on the information in Appendices 6.1 and 6.2, the costs and productivity of log haulage activity were calculated as follows (Box 6.2):

Box 6.2 Productivity and costs of log haulage

Productive time/basic time (PT):	AC + PL + LC + SL 255.60 + 90.70 + 0.37 + 89.17 = 435.84 s
Total time (TT):	PT + DE 435.84 + 2,916.00 = 3,351.84 s
Average size of log (volume):	5.27 m^3
Average distance for pulling of log (from stump to skid trail):	81.33 m
Productivity (basic time):	82.70 s m^{-3}
Productivity (total time):	636.02 s m^{-3}
Cost of machine:	RM 25.33 hr^{-1}
Cost of machine:	RM 0.96 m^{-3} (without operator)
Cost of operator:	RM 8.80 m^{-3}
Total cost of log haulage:	RM 9.76 m^{-3}

Based on the above calculations, the productivity of log haulage by RTH machine was 26.40 m^3 hr^{-1}, while the cost was RM 9.76 m^{-3}.

6.4.3 Log Skidding

The *itik* was handled by an operator. When the machine operator arrived at the temporary matau, the machine would be warmed up prior to the skidding of logs. The machine moved to the felling area through a skid trail. From Appendix 6.1**,** the time recorded for the machine to move from the temporary matau to the felling area was 480.50 s with a distance of 320.00 m. The logs at the road side of the skid trail would be sorted by the machine operator who attached/loaded four to five logs at the back of the *itik*. The loading time recorded for this activity was 444.83 s. Then the machine skidded out the logs from the felling area to the temporary matau. The travel time of the machine with the load of logs was 980.00 s with a distance of 320.00 m. When the machine arrived at the temporary matau, the logs would be released from the cable. The release time of log was 149.00 s. Most of the activity of this machine was sorting logs at the temporary matau. The delay time recorded was 3 271.00 s, including sorting the logs at the temporary matau and reconstructing the skid trail.

The elements involved in the productivity of log skidding were travel time (empty) (TE), loading time (LT), travel time (loaded) (TL), loosing cable from log (LG), and delay (DE). Based on the information in Appendices 6.1 and 6.2, the costs and productivity of log haulage activity were calculated as follows (Box 6.3):

Box 6.3 Productivity and costs of log skidding

Productive time/basic time (PT):	TE + LT + TL + LG 480.50 + 444.83 + 980.00 + 149.00 = 2,054.33 s
Total time (TT):	PT + DE 2,054.33 + 3,271.00 = 5,325.33 s
Average size of log (volume)	5.27 m^3
Average distance of log skidding (from skid trail to temporary matau):	320.00 m
Productivity (basic time):	395.06 s m^{-3}
Productivity (total time):	1 024.10 s m^{-3}
Cost of machine:	RM 24.67 hr^{-1}
Cost of machine:	RM 7.01 m^{-3} (without operator)
Cost of operator:	RM 27.50 m^{-3}
Total cost of log skidding:	RM 34.51 m^{-3}

Based on the above calculations, the productivity of log skidding by the *itik* machine was 3.52 $m^3 hr^{-1}$, while the cost was RM 34.51 m^{-3}.

6.4.4 Log Transportation

The lorry was also handled by an operator. This lorry was powered by a reconditioned six-cylinder engine. In the study area, the lorry was used for transporting logs from the temporary matau to the permanent matau, and transporting sand and wood residues for maintenance of the main road. The empty lorry moved from the permanent matau to the temporary matau in the early morning. The logging crew (machine operator and assistants) rode this lorry to go to the felling area. From Appendix 6.1, the time recorded for empty travelling (empty lorry) was 4,125.00 s.

The distance for empty travelling was 18,000 m. At the temporary matau, the lorry was loaded with logs. *Itik* was used to load logs onto the lorry. After the loading, the logs were tied up with a winch cable. The loading time was 825.00 s. Then the loaded lorry moved to the permanent matau. The time recorded for loaded travelling was 6,435.00 s with a distance of 18,000 m. When the lorry arrived at the permanent matau, the logs were released from the lorry. The release time was 157.50 s. The total delay time was 900.00 s.

The elements involved in the productivity of log transportation were travel time (empty) (TE), loading time (LT), travel time (loaded) (TL), unloading (UL), and delay (DE). Based on the information in Appendices 6.1 and 6.2, the costs and productivity of log transportation activity were calculated as follows (Box 6.4):

Box 6.4 Productivity and costs of log transportation

Productive time/basic time (PT):	TE + LT + TL + UL 4,125.00 + 825.00 + 6,435.00 + 157.50 = 11,542.50 s
Total time (TT):	PT + DE 11,542.50 + 900.00 = 12,442.50 s
Average size of log (volume):	1.68 m^3
Average distance of log transportation (from temporary matau to permanent matau):	18,000.00 m
Productivity (basic time):	6,870.24 s m^{-3}
Productivity (total time):	7,406.25 s m^{-3}
Cost of machine:	RM 33.03 hr^{-1}
Cost of machine:	RM 67.41 m^{-3} (without operator)
Cost of operator:	RM 2.75 m^{-3}
Total cost of log transportation:	RM 70.16 m^{-3}

Based on the above calculations, the productivity of log transportation by lorry was 0.49 m^3 hr^{-1}, while the cost was RM 70.16 m^{-3}.

Other costs were not calculated in this analysis. The calculated costs were only from the logging operation (Table 6.1). Log transportation shows the higher cost at RM 70.16 m^{-3} followed by skidding of logs at RM 34.51 m^{-3}. The total cost of timber extraction was RM 118.53 m^{-3} (RM215.51 t^{-1}).

Table 6.1 Total costs of timber extraction in PSF

No.	Item	RM m^{-3}	RM t^{-1}
1.	Cost of felling and cutting	4.10	7.45
2.	Cost of log haulage	9.76	17.75
3.	Cost of log skidding	34.51	62.75
4.	Cost of log transportation	70.16	127.56
	Total	118.53	215.51

Note: 1 tonne = 1.8 m^3

6.4.5 Outputs Model

Multiple linear regression was used to develop a linear model for felling, log haulage, log skidding and log transportation. All dependent variables were significant at 95%. The models for each activity are as follows:

i) Felling (chain-saw)

Felling = 16.287 + 0.027TT + 0.649CC + 1.539D

Note: TT = travel time/walking time from tree to tree

CC = cutting and decrowning
D = diameter of tree (dbh)

The model shows that travel time/walking from tree to tree and cutting were important in the felling activity. The chain-saw operator took 0.027 s to travel from tree to tree in 1 m. Felling time increased with increase in travel time, cutting time and diameter of tree.

ii) Log haulage (RTH)

Log haulage = 93.975 + 0.52AC + 23.90LC

Note: AC = attaching cable to log and tying-up
LC= loosing cable from log

The model shows that attaching cable to log and loosing the cable from the log affected the time of log haulage. The study showed that distance of haulage and volume of log did not influence the time of log haulage by the RTH.

iii) Log skidding using *itik*

Log skidding = 1338.914 + 0.151LC + 2.007VOL

Note: LC= loosing cable from log
VOL= volume of log

From the model, it was found that LC and VOL influenced the time of log skidding. Log skidding time increased with the increases in LC and VOL (number of logs skidded). The data collected for log skidding were less than thirty trips (samples) due to time constraint for this study. In this area, log skidding took five trips (five time cycles of log skidding) per day or thirty trips in six days. If the data collected were more than thirty trips, it is expected that more independent variables could be added to the above model.

iv) Log transportation using lorry

Log transportation = 2,497.602 + 2.138LT + 12.998UL + 74.629VOL

Note: LT= loading time
UL= unloading
VOL= volume of log

Data collected for log transportation were also for less than thirty samples. On average, this took five trips (five time cycles of log transportation) per day. Based on the data collected, the above model was developed. It was found that LT, UL and VOL influenced the log transportation time. It is also expected that more independent variables could be added to the above model if the data collected were for more than thirty trips (thirty time cycles).

6.5 CONCLUSIONS

The results of the productivity and time study are summarized in Table 6.2. From the table, the total cost of timber harvesting in the PSF of Pekan FR is RM118.53 m^{-3}. This cost is low because some of the other costs such as premium, Pre-F, road construction and tree marking were not included. Felling and log haulage were very productive compared with other activities. The productivities of *itik* and lorry were very low because most of the time with *itik* was consumed in constructing and maintenance of the skid trail, while the lorry was often used for carrying sand for road maintenance.

Table 6.2 Summary of the productivity and costs with each machine

Activity	Productivity	Cost	
Felling (chain-saw)	10.77 $m^3 hr^{-1}$	RM4.10 m^{-3}	RM20.99 $tree^{-1}$
Log haulage (RTH)	26.40 $m^3 hr^{-1}$	RM 9.76 m^{-3}	RM51.44 log^{-1}
Log skidding (*itik*)	3.52 $m^3 hr^{-1}$	RM34.51 m^{-3}	RM181.87 log^{-1}
Log transportation (lorry)	0.49 $m^3 hr^{-1}$	RM70.16 m^{-3}	RM117.87 log^{-1}
Total	-	RM118.53 m^{-3}	-

Appendix 6.1

i) Felling

	TT (s)	TR (m)	SC (s)	FL (s)	CC (s)	NL	DIA (cm)	SP	DE (s)	LL (m)	Vol (m^3)
Total	4,320.00	597.00	2,183.57	5,364.74	3,673.55	30.00	1,744.50	-	35,820.00	545.80	153.52
Avg.	144.00	19.90	72.79	178.82	122.45	1.00	58.15	-	1,194.00	18.19	5.12

Description

TT - Travel from tree to tree
TR - Travel distance
SC - Clearing around the stump of tree before felling
CC - Cutting
NL - No. of logs
DIA - Diameter of logs
SP - Species
DE - Delay
LL - Length of logs
Vol - Log volume

ii) Rimbaka timber harvester (RTH)

	AC	PL	TD 2	LC	SL	DE	DIA	LL	NL	vol (m^3)
	(s)	(s)	(m)	(s)	(s)	(s)	(cm)	(m)		
Total	7,668.00	2,721.00	2,440.00	11.23	2,675.00	87,480.00	1,756.50	553.20	30	158.14
Average	255.60	90.70	81.33	0.37	89.17	2,916.00	58.55	18.44	1	5.27

Description

AC - Attaching cable to log and tying
PL - Pulling log from stump
TD2 - Pulling distance
LC - Loosing cable from log
SL - Sorting log
DE - Delay time
DIA - Diameter of logs
LL - Length of logs
NL - No. of logs
Vol - Log volume

iii) Traxcavator (*Itik*)

	TE (s)	TD1 (m)	LT (s)	NL	DIA (cm)	LL (m)	TL (s)	TD2 (m)	LG (s)	DE (s)	Vol (m^3)
Total	2,883.00	1,920.00	2,669.00	30	1,742.50	552.40	5,880.00	1,920.00	894.00	19,626.00	156.09
Average	480.50	320.00	444.83	1	58.08	18.41	980.00	320.00	149.00	3,271.00	5.20

Description

TE - Travel time (empty)
TD1 - Travel distance (empty)
LT - Loading time (sorting and attach log)
NL - No. of logs
DIA - Diameter of logs
LL - Length of logs
TL - Travel time (load)
TD2 - Travel distance (load)
LG - Loosing cable from logs
DE - Delay time
Vol - Log volume

iv) Lorry

	TE (s)	TD1 (m)	LT (s)	NL	DIA (cm)	LL (m)	TL (s)	TD2 (m)	UL (s)	DE (s)	Vol (m^3)
Total	16,500.00	72,000	3,300.00	65	3,683.00	428.60	25,740.00	72,000	630.00	3,600	109.25
Average	4,125.00	18,000	825.00	1	56.66	6.59	6,435.00	18,000	157.50	900	1.68

Description

TE - Travel time (empty)
TD1 - Travel distance (empty)
LT - Loading time
NL - No. of logs
DIA - Diameter of logs
LL - Length of logs
TL - Travel time (load)
TD2 - Travel distance (load)
UL - Unload
DE - Delay time
Vol - Log volume

Appendix 6.2 Cost information

Item	**Felling**	**RTH**	**Transporter/*itik***	**Lorry**
Machine operator (RM t^{-1})	7.00	16.00	50.00	5.00
Petrol/diesel consumption (litres day^{-1})	10.00	120.00	120.00	151.00
Price of petrol/diesel (RM $litre^{-1}$)	1.92	2.00	2.00	2.00
Total working days $month^{-1}$	25	25	25	25
Total working hours day^{-1}	10	10	10	10
Cylinder oil consumption (litres day^{-1})	0.02	0.80	0.72	3.79
Price of cylinder oil (RM $litre^{-1}$)	5.00	5.00	5.00	5.00
Bought price (RM)	2,400	190,000	90,000	80,000
Sale price (RM)	2000	150,000	80,000	30,000
Depreciation (RM)	400	40,000	10,000	50,000
Life span (yr)	5	20	15	15

CHAPTER SEVEN

HYDROLOGICAL RESPONSE TO ROAD CONSTRUCTION AND FOREST LOGGING IN A PEAT SWAMP FOREST

By

Marryanna Lion, Siti Aisah Shamsuddin & Saiful Iskandar Khalit

7.1 INTRODUCTION

Peat swamp forest (PSF) is usually located immediately behind the coastline and extends inland along the lower reaches of the main river systems. It is a waterlogged forest growing on a layer of dead leaves and plant material up to 20 m thick. Peat swamp forest provides a variety of benefits such as forestry and fishery products, energy as biomass, carbon store, flood mitigation, water supply and groundwater recharge.

As far as peatland is concerned, its hydrological characteristics are among the important aspects that regulate the ecosystem in the PSF. According to the DANIDA Technical Report (2004), water fluctuation is a very important factor in the colony development of the flora and fauna. Hence, a study was carried out to examine the hydrological response to the establishment of a road due to forest logging activities. It was reported by DANIDA that the general impact from the road system in PSF is generally low. The main impact of the road system is the diversion of surface water which creates congestion of water in the impacted log extraction corridors and probably dries up places in between the corridors. However, the impact varies with the method of road construction. This study in Compartment 77, Pekan PSF, was focused on the impact of the construction of a 2,000-m long forest road on the hydrology conditions in the PSF. This road was constructed using a few foundation layers such as redger wood and sand to compact the road.

Since the hydrological components are important factors that influence the ecosystem of the PSF, four interrelated hydrological components were monitored in the study. These were groundwater level (GWL), infiltration, soil compaction and soil moisture.

Groundwater can be defined as any water that is stored below the surface of the ground. Meanwhile, soil moisture measures the percentage of water available in the soil. Watertable is a surface of the saturated zone, below which all soil pores or rock fractures are filled with water. Lowering watertables and opening up the forest canopy promote the risk of fire in peat soils (Sahabat Alam Malaysia 2008). Fire that takes hold in dry surface biomass spreads rapidly (Frandsen 1997). Fire produces large gaps in the forest leading to increased wind circulation which, when combined with greater penetration of sunlight to the forest floor, encourages rapid growth of secondary understorey vegetation. As a result, temperature and humidity increase while soil moisture decreases adding greatly to the susceptibility of the landscape to subsequent fires. In this way, initial fire damages the remaining forest severely and increases the risk of recurrent fires significantly (Siegert *et al.* 2001). This destructive sequence of events can be stopped only by rewetting the peatland and reinstating the hydrological integrity of the ecosystem (Wosten & Ritzema 2001).

The study by Wosten *et al.* (2008) shows that proper water management is a key element in the wise use of peatlands. In dry years, groundwater levels drop below the critical threshold of 40 cm. Deep groundwater levels mean an increased subsidence of the peat by oxidation as well as an increase in fire susceptibility. Both oxidation and fire transform peat lands from carbon sinks under pristine conditions into carbon sources with important local, regional and global consequences under drained conditions (Wosten *et al.* 2008). In wet years, flooding depth and flooding duration have adverse consequences for the restoration potential of peat lands. Wosten *et al.* (2008) also added that ideally, groundwater levels should vary between 40 cm below and 100 cm above the land surface.

Besides, other factors such as topographic features are also important in affecting the watertable in PSF areas. Normally the dome-shaped surface of the peat swamps causes rainwater to drain off to different sides. In fact, this situation divides a peat swamp into several catchments (Ritzema & Wosten 2004).

Infiltration is a process by which water on the ground surface enters the soil. The infiltration rate can be simply defined as how fast water enters the soil. In this study, an infiltrometer was used to determine the infiltration rate of the soil. Infiltration is influenced by soil compaction because of the decrease in size of the soil pores. When the infiltration rate is slow, it will stimulate more overland flow or surface runoff. Whatever reduces the rate of water movement through the soil produces slower soil profile drainage by subsurface (tile) drains. Soil compaction is the mass of soil particles divided by the volume they occupy (space between particles).

The soil bulk density was also determined with construction of the forest road. Bulk density is typically expressed in g cm^{-3} usually given on an oven-dry (110 °C) basis. It is calculated as the dry weight of soil divided by its value. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is dependent on soil texture and the densities of soil mineral (sand, silt and clay) and organic matter particles, as well as their packing arrangement. Bulk density typically increases with soil depth since subsurface layers have reduced organic matter, aggregation, and root penetration compared with surface layers and therefore, contain less pore space. Subsurface layers are also subject to the compacting weight of the soil above them. The wetting and drying cycles that occur in soils naturally, generally do very little to alter soil bulk density. Variation in bulk density is attributable to the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil. Most mineral soils have bulk densities between 1.0 and 2.0 g cm^{-3}.

Bulk density is an indicator of soil compaction. High bulk density is an indicator of low soil porosity and soil compaction. It may cause restrictions to root growth, and poor movement of air and water through the soil. Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield and reducing vegetative cover available to protect soil from erosion. By reducing water infiltration into the soil, compaction can lead to increased runoff and erosion from sloping land or waterlogged soils in flatter areas. In general, some soil compaction to restrict water movement through the soil profile is beneficial under arid conditions, but under humid conditions compaction decreases yields.

7.2 MATERIALS AND METHODS

7.2.1 Study site

The study was conducted in Compartment 77 (experimental plot) and Compartment 78 (control plot) at Pekan Forest Reserve (FR), Pahang. Compartment 77 was divided into Plots 77A and 77B (Figure 7.1) through which a road had been constructed. Compartment 78 was a virgin PSF or intact forest where no harvesting had been conducted.

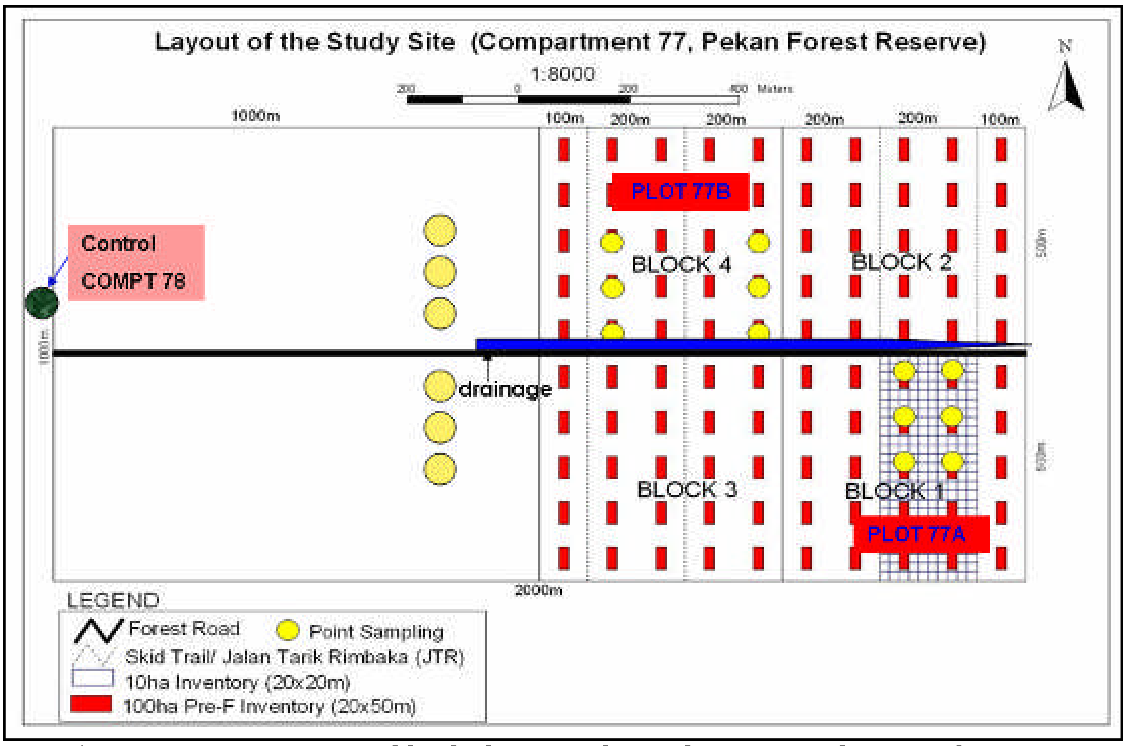

Figure 7.1 Experimental hydrologic study in plots 77A and 77B, Pekan FR

The forest road was constructed in 2005 with 8-m width and 2,000-m length. Uncommercial tree species with diameter of 20 cm and above were used as foundation in its construction before the redger wood was placed as a second layer and it was finally covered with sand as the upper road surface layer (Figure 7.2).

Figure 7.2 Redger wood used as the middle layer and sand cover as the top layer in the forest road construction

7.2.2 Measurements of parameters

i) Groundwater level (GWL)

Groundwater level was measured using piezometers made of PVC pipe with 2.5-m length and 8.0-cm diameter inserted under the ground surface as a casing of a well (Figure 7.3). During normal days the water level was detected at 1.0–1.5 m below the surface. The water level increased nearer to the surface during heavy rainfalls. So the PVC casing was dug into the ground until the water level was found. The height of the remaining PVC from the ground surface (B) was measured (Figure 7.3). A measuring tape was used to measure the water level (A) from the top of the PVC (refer to Figures 7.3 and 7.4).

The water-level at the depth below the surface (DBS) is calculated as:

Depth below surface (DBS), C = B - A

Where,

A = total length of cable (PVC height to water-level)
B = height of PVC casing from the top to ground level

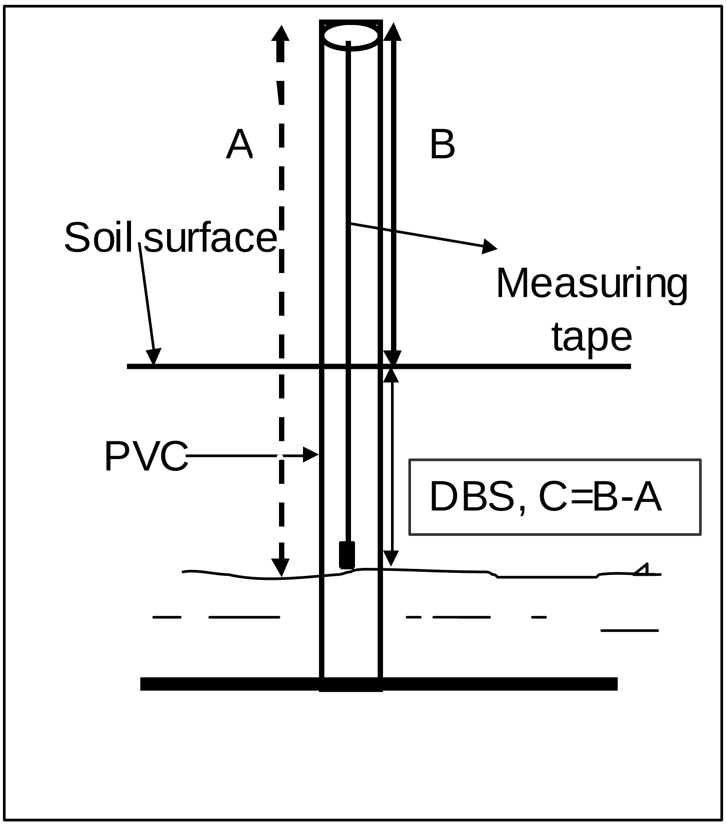

Figure 7.3 Experimental design of a conventional method to measure the groundwater level

Figure 7.4 Measuring tape and PVC pipe to measure the groundwater level.

To monitor the groundwater level, measurements were made at 12 wells established in the experimental (Plot 77A &77B) and control plots (Plot 78) . The wells were set up perpendicular to the road with the nearest well to the roadside being 40 m from the edge of the road. Out of the 12 wells in the experimental plots, six were designed at intervals of 200 x 100 m in Plot 77A while in Plot 77B two transects with three wells were established at 100-m distance apart (refer to Figure 7.1).

ii) Infiltration rate determined on the surface of the forest road

A number of 5–8 units of infiltrometer were set up over the road depending on the surface condition and road width. The distance from one transect to another was 200 m and from one unit to another 50 m (Figure 7.5). Each PVC infiltrometer of 8.5-cm diameter and 13 cm height from the surface was inserted into the soil (Figure 7.6). A stopwatch was used to measure the infiltration rate after a volume of water was poured into the infiltrometer ring and the water level was recorded after 30 min. A number of 31 samples were collected from the road site and another samples from Plot 78. The infiltration rate was calculated as below:

Infiltration rate, Q (cm^3s^{-1}) = velocity ($cm\ s^{-1}$) x area (cm^2)

Q = VA

where,

Q = infiltration rate
V = velocity
A = area

$$\text{Velocity, } v = \frac{\text{infiltration (cm)}}{\text{time (seconds,s)}}$$

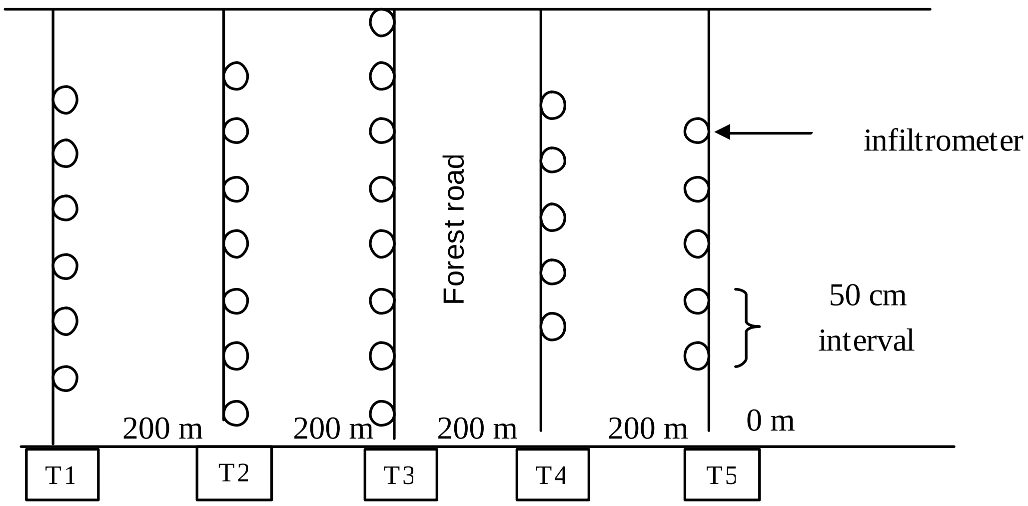

Figure 7.5 Schematic diagram of infiltration measurements in the field

Figure 7.6 Measurements of infiltrations (left) and storage of peat soil in soil core tube for soil moisture sampling (right)

iii) Soil bulk density

The soil sampling was conducted using soil core tube of 5.0-cm diameter and 5.0-cm height (volume of 98.2 cm^3). The soil core was inserted carefully into the soil surface until the soil sample completely filled the tube. The soil sampling was done at the same area where an infiltrometer was set up on the surface of the road. Only four transects were selected and two soil samples were taken from each transect. There were eight samples which were sealed and brought back to the laboratory for analysis. The bulk density value was obtained using the following equation:

Bulk density (Bd_u) = mass of soil sample (m)/volume of soil sample (v)

$Bd_u = m/v$

where,

m = mass of soil (unit = g)
v = volume of soil sample (unit = cm^3)

iv) Soil moisture

The measurement of *ex-situ* soil moisture was conducted using the gravimetric method. Figure 7.6 shows a sample obtained from the field from a site where a monitoring well was set up. Altogether 13 samples were collected.

Each sample was analysed in the laboratory by determining the difference between the moist weight and oven-dry weight which is the mass of water contained by the soil at the time the sample was collected.

7.2.3 Data collection

Monthly field visits and data collections were conducted before logging (August–September 2006), during logging (October 2006 – May 2007), however the logging operation stopped in December–February 2007 and resumed in March 2007 until May 2007, and after logging (June–August 2007). There was no measurement and forest activity in the study area from December 2006 to February 2007 due to the monsoon season.

7.3 RESULTS

7.3.1 Groundwater level (GWL)

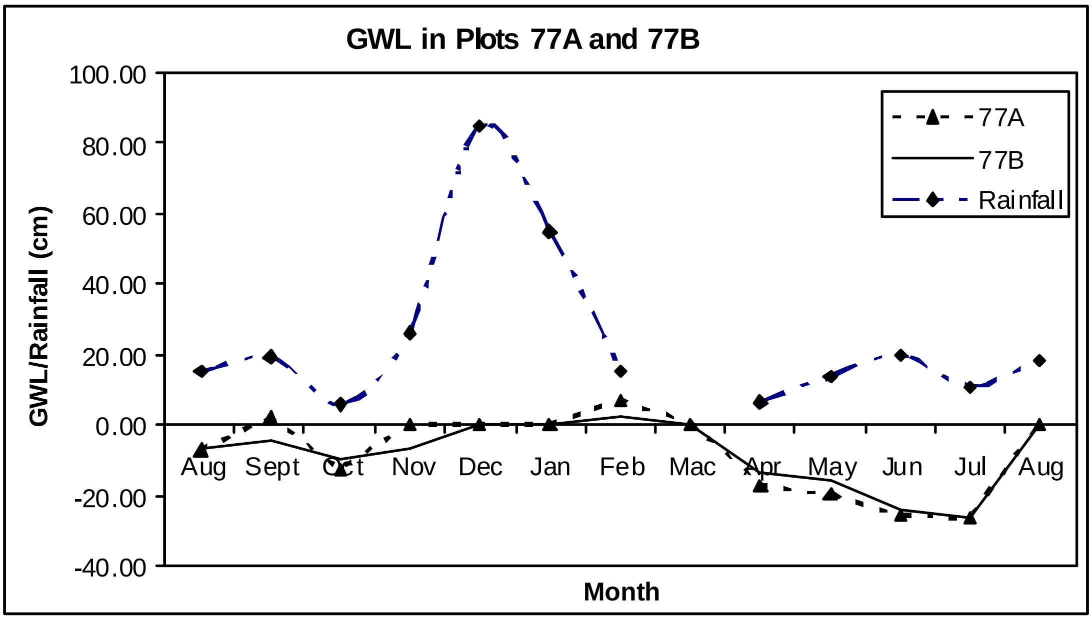

Figure 7.7 Groundwater level before, during and after logging in Plots 77A and 77B at Pekan FR in 2006 – 2007

The monthly rainfall data were obtained from the Department of Irrigation and Drainage (DID) of Runchang Station. Even though the station is located outside the forest reserve and the amounts of rainfall observed could be slightly different from those inside the forest reserve, they were used as reference to the GWL data obtained. Figure 7.7 shows that in both areas, the water level followed the rainfall pattern except during the heavy rainy season from December 2006 to January 2007 which data were not available and during the dry season from April to July 2007. Thus the GWL was strongly influenced by the rainfall events. There was not much difference in values between Plots 77A and 77B where during May to September the water level was always below the ground surface and the area was flooded during November to March.

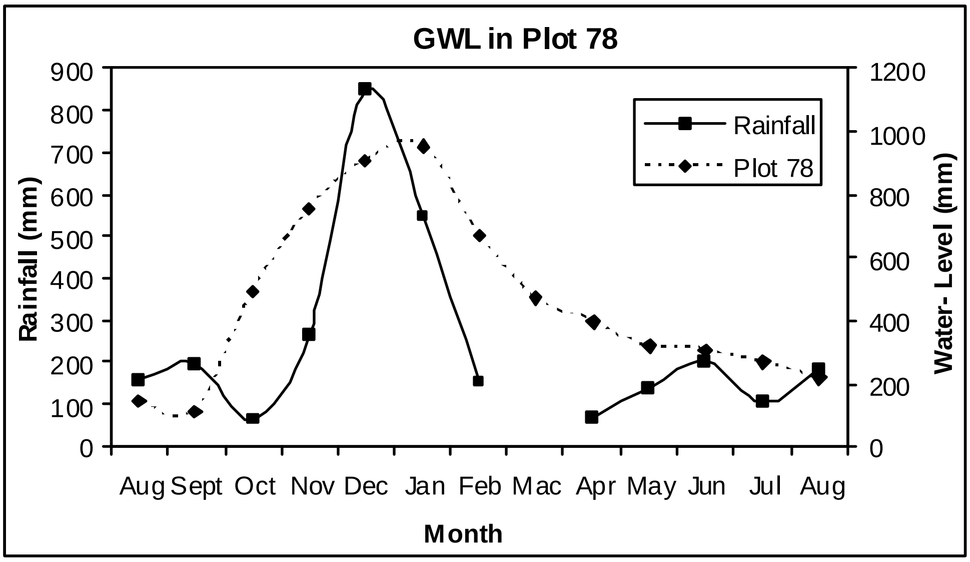

Figure 7.8 Monthly rainfalls and water-level in 2006 – 2007 observed in the Plot 78

Figure 7.8 shows that the water-level in Plot 78 was always at higher level than ground surface. Hence, the ground surface of this area was covered with water all the year round. The water-level also followed the rainfall pattern with the water-level was as high as 100 cm and as low as 10 cm above the ground surface. In Plot 77A and 77B by comparison, the GWL was as low as 30 cm below the ground surface. There were several factors that affect the fluctuation in water-level. Among the reasons are vegetation density, topography and evapotranspiration.

Figures 7.9 and 7.10 shows that the GWL obtained from wells located 40, 100 and 200 m from the roadside in Plots 77A and 77B. During the dry season, from April to July 2007, the GWL at 100 m distance from the roadside was higher than that at 200-m distance. But from June to July 2007, the GWL increased as it got farther the roadside. During the wet season, even though the pattern was not consistent as water-level was very close to the ground surface, at +/- 10 cm but it decreased with distance from the roadside.

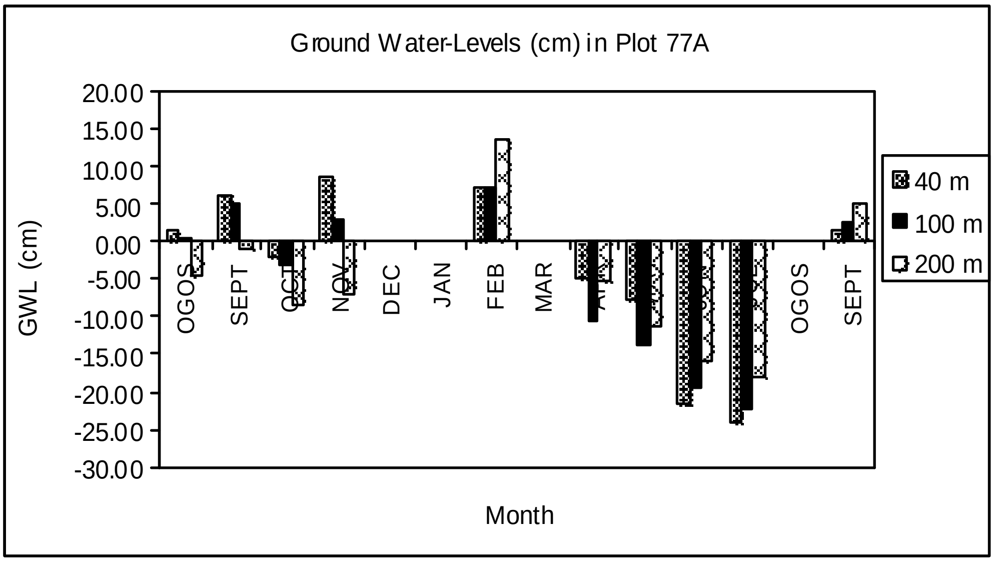

Figure 7.9 GWL obtained from the wells at three distances from the roadside (Plot 77A) in 2006-2007

In plot 77B from May to July, GWL at 100 m distance increased to become the highest while the GWL at 200 m distance increased faster than that at 40 m distance. The pattern for February 2007 (just after the wet season) in Plot 77B was different from that in Plot 77A.

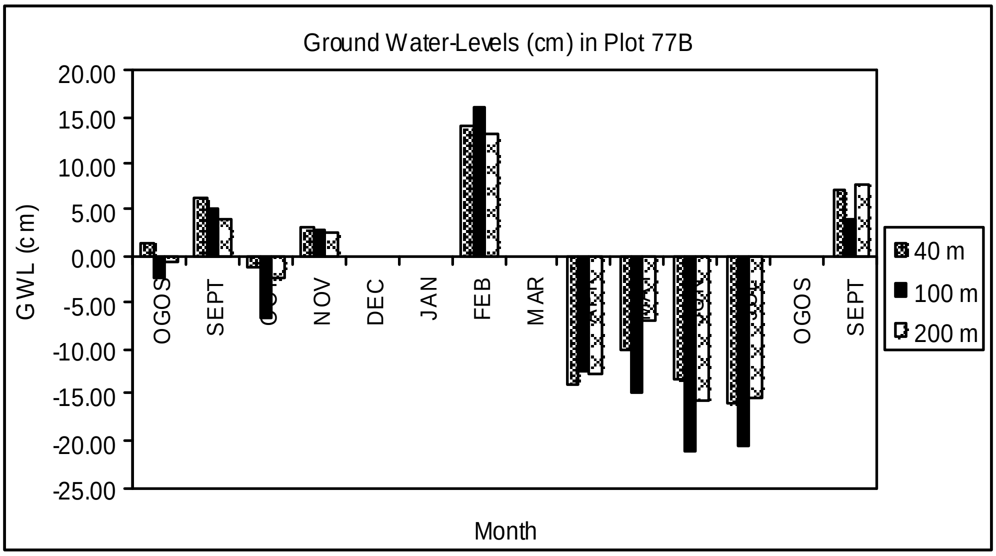

Figure 7.10 GWL obtained from the wells at three distances from the roadside (Plot 77B) in 2006-2007

7.3.2 Infiltration rate

Table 7.1 Infiltration rates (cm^3s^{-1}) at Pekan FR

	Average (August – September 2006)	Average (February -August 2007)
Road site	0.0955	0.0548
Plot 78	n.a.	1.1715

n.a. = not available

Table 7.1 shows that the infiltration rates observed at the road surface changed with the logging operation. Before logging (August – September 2006), the average of infiltration rate was higher compared with the rate after logging. In the undisturbed forest (Plot 78), an average of infiltration rate was accumulated and higher compared with the values obtained from the road site. The average absorption rate of the PSF road was found to be very low at 0.25 mm min^{-1} compared with the residual forest (127 mm min^{-1}) and skid trail (6.1 mm min^{-1}). The more compacted soil of the road surface resulted in smaller pore volume and lower water absorption.

7.3.3 Soil bulk density

Table 7.2 Bulk density (g/cm^{-3}) at Pekan FR

	Average	Max	Min	Standard deviation (SD)
T1	1.30	2.402	0.029	0.951
T2	1.17	2.273	0.028	0.969
T3	1.11	2.161	0.002	0.863
T4	1.18	2.297	0.019	0.958

Periods of measurements: (August – November 2006) and (February - August 2007)

Table 7.2 shows that the bulk density near the forest road at the four locations had values that did not much differ from one location to another. The bulk density obtained from these locations ranged from 0.019 to 2.4 g/cm^{-3}. The bulk density was only measured in Plot 77A and B. There was no bulk density measurement conducted at control plot.

7.3.4 Soil moisture content

Table 7.3 Soil moisture (%) at Pekan FR

	Average	Max	Min	Standard deviation (SD)
Plot 77A	78.6	82.7	75.0	2.2
Plot 77B	79.2	83.7	71.6	4.2
Plot 78	80.8	85.9	77.7	3.2

Periods of measurements: (Aug 06 – Nov 06) and (Feb 07-Aug 07)

The soil moisture values obtained for the three locations (Table 7.3) were considered high reaching up to 80%. Even though there was not much difference in soil moisture content between the logged forest and undisturbed forest, the values for the former were a little bit lower than for the latter. The soil moisture contents were about 71.6–83.7% (logged forest) and 77.7 – 85.9% (undisturbed forest).

7.4 DISCUSSION

Peat lands receive water from their surrounding areas, as in the Pekan FR, Pahang, where the peat deposit, due to its flatness, acts as a buffer and delays or slows the discharge of water during dry seasons. In opposite, water level is recharged by precipitation. The high water -level after the monsoon (November-March) was due to water infiltrated into the soil and water table as well. In the dry season (April-July), the water table will be at a greater depth compared to the wet season, and this varies seasonally.

Damage to the soil due to the road construction was evaluated by comparing the mean soil bulk densities between the experimental and the control plots. High bulk density means more compaction, hence less infiltration. Soil compaction reduces the movement of water through the soil (saturated hydraulic conductivity), with increases in runoff. Rain is normally absorbed into the soil faster than it can fall, and overland flow occurs only on areas where water infiltration is impaired by heavy compaction and exposed soil. Heavy equipment during road construction and road use during log transport can squeeze soil pores, reducing the space for water and air.

Results showed that the road construction affects the water level which during the wet season near the roadside was higher than inside the forest. The compaction by the road establishment and the road being higher than the ground level of the forest resulted in surface flow into the drainage system and increased water level near the roadside during the wet season.

The study being more focused on the hydrological characteristics of the PSF as a result of a road construction for logging activities, the question of how the road affected the growth of small trees in the area was not easy to determine. Had the water level been measured before the road construction together with the rainfall in the same area it could have used to compare the water level measures during and after the road construction to give some idea of how the changes in water level had influenced the survival of the small trees in that plot. The tree measurements could have been conducted prior to and after the road construction. Naturally, the standing tree species have adapted themselves to the water-logged condition of the PSF area.

7.5 CONCLUSIONS

A more detailed study of the road impact on the hydrological characteristics in PSF needs to be carried out as this study provided only general information on the water-level, soil infiltration, soil bulk density and soil moisture condition in the area where there was already an establishment of forest road. From the results, the water-level of the undisturbed forest ranged from 10 to 70 cm above the surface while in the areas involved with logging it was 10 cm above and 30 cm below the surface. The infiltration rate of the undisturbed forest was much higher than that of the road surface with average values of 1.1715 and 0.0548 cm^3s^{-1} respectively. The average soil bulk density of the forest road was 1.19 gcm^3 and higher soil moisture was observed in the undisturbed forest with value of up to 80%. Soil bulk density does not determined in control plot.

CHAPTER EIGHT

DEVELOPMENT OF A LOCAL VOLUME TABLE (LVT) FOR *GONYSTYLUS BANCANUS* IN PEKAN FOREST RESERVE

By

Ismail Parlan, Abd Rahman Kassim, Wan Mohd Shukri Wan Ahmad, Samsudin Musa & Harfendy Osman

8.1 INTRODUCTION

Gonystylus bancanus locally known as ramin melawis is not only the main species of *Gonystylus* (Soerianegara & Lemmens 1994), but also the main timber of peat swamp forests (PSF). The species is also amongst the main commercial timbers produced from the forests of Malaysia and Indonesia (Soerianegara & Lemmens 1994, Abdullah *et al.* 2004, MTIB 2004).

Gonystylus spp. was officially listed under Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) effective from 12 January 2005. This requires that traded *Gonystylus* spp. timbers meet the requirements of sustainable production. *Gonystylus bancanus* represents the major source of ramin timber compared with other *Gonystylus* spp. from dry inland forests. Therefore, sufficient information on *G. bancanus* is important in preparing the non-detrimental findings (NDF) that should be conducted by the scientific authority (SA) to set the annual quota for the trade. This study was aimed to develop a local volume table (LVT) specifically for *G. bancanus* in Pekan FR, Pahang.

8.2 MATERIALS AND METHODS

8.2.1 Study Site

Data were collected from Compartment 77, Pekan Forest Reserve (FR), Pahang as described in Chapter 1. This area is categorized as Ramin-Bintangor subtype, representing an area of about 10 000 ha of Pekan FR.

8.2.2 Selection and Measurements of Sample Trees

All measurements were carried out on standing trees. In preparing the volume table, preferably trees with ≥15 cm in dbh as discussed by Nurhajar *et al.* (2010) should be selected. Nevertheless, in this study, the smallest *G. bancanus* recorded was of 28.2 cm dbh, while the biggest sample tree was of 83.4 cm dbh. A total of 68 trees of *G. bancanus* were sampled in this study (Figure 8.1 and Table 8.1). The calculated volume of each sample tree ranged between 0.61 and 8.36 m^3. The number of samples is sufficient to be used for developing the LVT based on the prescription given by Awang Noor and Mohd Radhi Chu (2002).

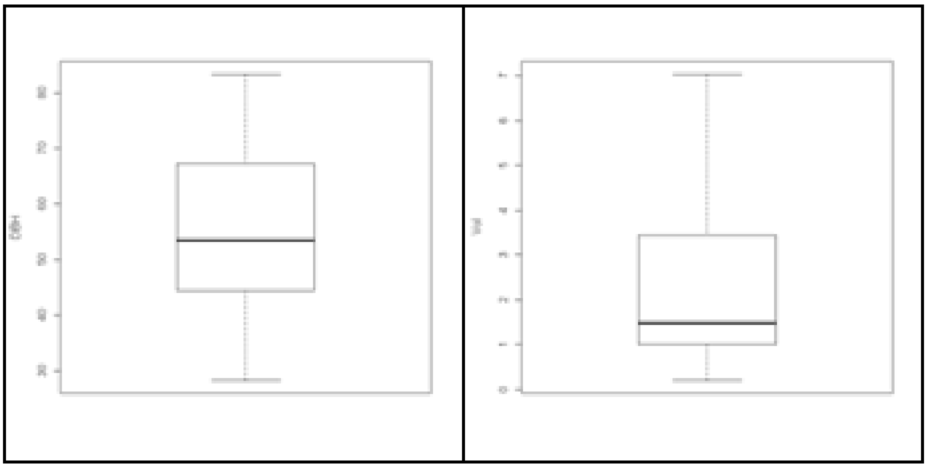

Figure 8.1 Boxplots of dbh and volume of sample trees of *G. bancanus* in Compartment 77, Pekan FR

Table 8.1 Summary statistics of sampled *G. bancanus* trees in Pekan FR

Statistical parameter	Dbh (cm)	Volume (m^3)
Minimum	28.20	0.6171
1st quartile	44.65	2.0846
Mean	53.50	3.2335
Standard deviation	13.78	1.5753
Median	55.16	3.6832
3rd quartile	67.10	5.3114
Maximum	83.40	8.3611

The measurements of parameters were done using a Handheld Laser Criterion 400 and recorded in a standard form devised for this study. The parameters measured in this study were:

- base diameter in cm (stump height);
- dbh in cm (1.3 m above ground level);

- total height in m (measured from the predetermined height of ground till the crown point);
- merchantable height in m (stump height up to first main branch);
- stem diameter (over bark) in cm (measured for every 2-m interval, from the stump height up to last complete 2-m section); and
- stem diameter (over bark) in cm (measured for final section from the last complete 2-m section up to the first main branch).

Data collected were analysed in two stages. The first stage involved computing the volume for each section and then summing up for the whole tree. The second stage involved regression analysis, i.e. to fit the data to the selected equations in order to seek the best volume equation (best-fitted model).

8.2.3 Individual Tree Volume Calculations

The tree volume of each 4-m section was calculated using Newton's formula:

$$V = 0.0000524 * (Dl^2 + 4 Dm^2 + Ds^2)$$

where,
V = volume
Dl = diameter at large end
Dm = diameter at the middle
Ds = diameter at small end

For the final section, Smalian's formula was used:

$$V = (B + b)/2] * L$$

where,
V = volume
B = cross-sectional area at the large end of the log
b = cross-sectional area at the small end of the log
L = log length

For each individual tree, the volumes of sections were then added to give a total tree volume.

8.2.4 Constructing Volume Equations

The method of least squares was used for the construction of volume equations. Nine equations using both unweighted and weighted models [to stabilize the variance of the residuals – Wan Razali *et al.* (1989)] were developed (Table 8.2).

Table 8.2 Developed equations of models

Model no.	Equation	Weight
1	$V=a_0+a_1dbh$	-
2	$V=a_0+a_1dbh+a_2dbh^2$	-
3	$V=a_0+a_1dbh^2$	-
4	$Ln(V)=a_0+a_1Ln(dbh)$	-
5	$V=a_0*dbh^{a1}$	-
6	$V=a_0+a_1dbh+a_2dbh^2$	$1/dbh^2$
7	$V=a_0+a_1dbh^2$	$1/dbh^2$
8	$V=a_0+a_1dbh^2$	1/dbh
9	$V=a_0+a_1dbh+a_2dbh^2$	1/dbh

*a_0, a_1, a_2= constants

The individual tree volumes derived from the sampled trees were regressed with the equations using R statistical software (R Development Core Team 2010). With the inclusion of transformations of the dependent variable and weighted regressions into the analysis, there is a regression bias in comparing these equations. Furnival's index (FI) was used to overcome the regression bias [Furnival (1961) as cited in Wan Razali *et al.* (1989)]. The equation with the smallest FI indicates the best-fitted model.

Furnival's index is expressed as follows:

$$FI = [f'(V)]^{-1}s$$

where,

FI	= Furnival's index
$[f'(V)]^{-1}$	= the geometric mean of the derivative of the dependent variable with respect to volume
s	= the residual standard error from the fitted regression

8.2.5 Comparing Total Volumes of Trees Using Volume Equations and Forest Checking Station Data

Forest Checking Station (FCS) data for *G. bancanus* trees harvested from Compartment 77, Pekan FR, were used to determine the total volume of each volume equation. As FCS data produce net volumes, logically the equation developed in this study should produce higher volume estimation as it estimates gross volume.

8.3 RESULTS & DISCUSSION

8.3.1 Selected Model

Nine equations were tested. Results of the regression analysis are summarized as in Table 8.3. The log-log model [*Ln(V)= -7.2213+2.1057Ln(dbh)*] was selected as it exhibited the smallest FI.

Table 8.3 Summary of results of the regression analysis

Model no.	a_0	a_1	a_2	R-squared	Residual standard error (RSE)	Geometric mean (GM)	Furnival's index (FI)
1	-3.2905	0.1264	-	0.8542	0.7255	1.0000	0.7255
2	-0.9756	0.0369	0.0008	0.8616	0.7124	1.0000	0.7124
3	-0.0005	0.001	-	0.8604	0.7102	1.0000	0.7102
*4	-7.2213	2.1057	-	0.8990	0.1883	0.3157	0.5965
5	0.0013	1.9766	-	-	0.7099	1.0000	0.7099
6	-1.1459	0.0437	0.0007	0.8922	0.0116	0.0004	32.9172
7	-0.0926	0.0012	-	0.8899	0.0116	0.0004	33.0311
8	-0.0455	0.0012	-	0.8766	0.0902	0.0187	4.8149
9	-1.0863	0.0412	0.0008	0.8783	0.0903	0.0187	4.8165

*Model no. 4 = best-fitted model

8.3.2 Development of Local Volume Table (LVT)

Based on the FI, the final volume equation (volume over bark) of *G. bancanus* for Pekan FR is as follows:

$$Ln(V) = -7.2213 + 2.1057\ Ln(dbh)$$

where,
V = merchantable volume (m^3)
dbh = diameter at breast height (cm)

Based on the equation, an example of LVT constructed for *G. bancanus* in Pekan FR is as given in Table 8.4. The scatter plots of actual volume and dbh with overlay of the predicted volume are shown in Figure 8.2.

Table 8.4 Example of LVT for *G. bancanus* in Pekan FR

dbh (cm)	Vol. (m^3)	Dbh (cm)	Vol. (m^3)	Dbh (cm)	Vol. (m^3)	Dbh (cm)	Vol. (m^3)
30.0	0.9423	33.0	1.1518	36.0	1.3834	39.0	1.6373
30.1	0.9490	33.1	1.1591	36.1	1.3915	39.1	1.6462
30.2	0.9556	33.2	1.1665	36.2	1.3996	39.2	1.6551
30.3	0.9623	33.3	1.1739	36.3	1.4077	39.3	1.6640
30.4	0.9690	33.4	1.1814	36.4	1.4159	39.4	1.6729
30.5	0.9757	33.5	1.1888	36.5	1.4241	39.5	1.6818
30.6	0.9825	33.6	1.1963	36.6	1.4324	39.6	1.6908
30.7	0.9892	33.7	1.2038	36.7	1.4406	39.7	1.6998
30.8	0.9960	33.8	1.2113	36.8	1.4489	39.8	1.7088
30.9	1.0028	33.9	1.2189	36.9	1.4572	39.9	1.7179
31.0	1.0097	34.0	1.2265	37.0	1.4655	40.0	1.7270
31.1	1.0166	34.1	1.2341	37.1	1.4739	45.0	2.2131
31.2	1.0235	34.2	1.2417	37.2	1.4823	50.0	2.7628
31.3	1.0304	34.3	1.2494	37.3	1.4907	55.0	3.3768
31.4	1.0373	34.4	1.2571	37.4	1.4991	60.0	4.0559
31.5	1.0443	34.5	1.2648	37.5	1.5075	65.0	4.8004
31.6	1.0513	34.6	1.2725	37.6	1.5160	70.0	5.6112
31.7	1.0583	34.7	1.2803	37.7	1.5245	75.0	6.4885
31.8	1.0653	34.8	1.2880	37.8	1.5330	80.0	7.4330
31.9	1.0724	34.9	1.2959	37.9	1.5416	85.0	8.4451
32.0	1.0795	35.0	1.3037	38.0	1.5502	90.0	9.5253
32.1	1.0866	35.1	1.3115	38.1	1.5588		
32.2	1.0938	35.2	1.3194	38.2	1.5674		
32.3	1.1009	35.3	1.3273	38.3	1.5761		
32.4	1.1081	35.4	1.3353	38.4	1.5847		
32.5	1.1153	35.5	1.3432	38.5	1.5934		
32.6	1.1226	35.6	1.3512	38.6	1.6022		
32.7	1.1298	35.7	1.3592	38.7	1.6109		
32.8	1.1371	35.8	1.3672	38.8	1.6197		
32.9	1.1444	35.9	1.3753	38.9	1.6285		

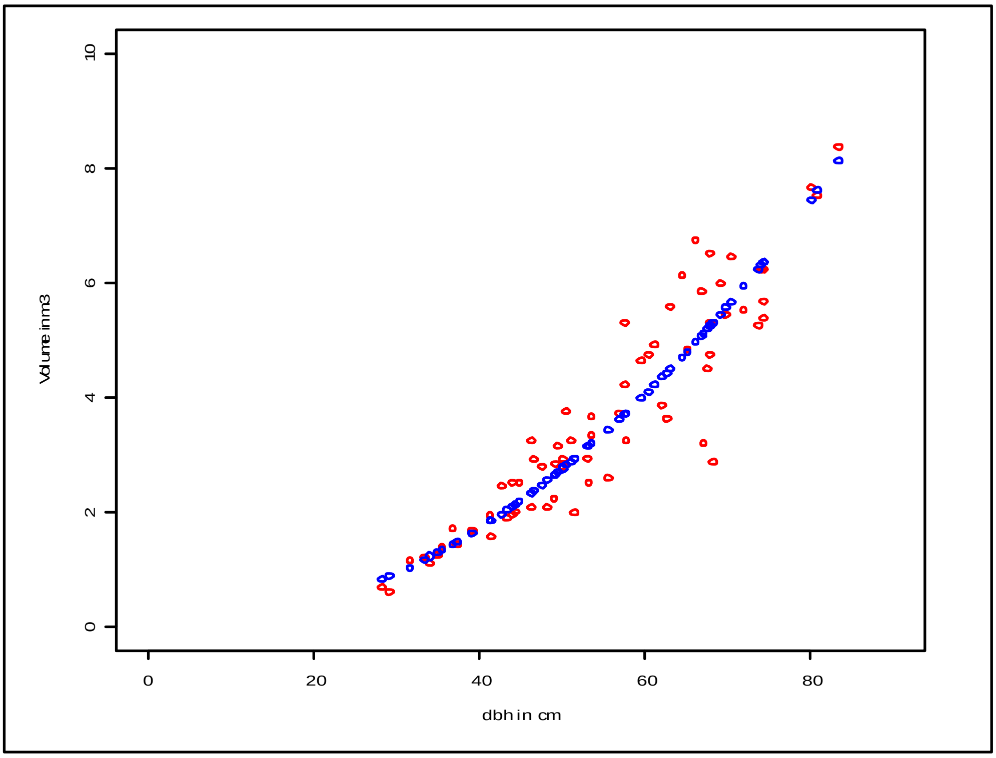

Figure 8.2 Scatter plots of actual (red in colour) and predicted (blue in colour) tree volume of *G. bancanus* in Pekan FR

8.3.3 Comparison with Forest Checking Station Data

Using the volume equations, we estimated and compared timber volumes of Pekan FCS of *G. bancanus* harvested from Compartment 77, Pekan FR (Table 8.5). Data of the Pekan FCS act as validation of the formula developed. Ground verification could not be done on the field due to non-available suitable site as no logging activity was being conducted (end of 2010 to early 2011).

A total of 366 trees (minimum 50 cm dbh) of *G. bancanus* with complete dataset recorded in the Pekan FCS produced a volume of 1,499.6 m^3. The selected LVT for *G. bancanus* in Pekan FR (Model No. 4) produced an reasonable estimated volume of 17.5% higher than the volume produced by the FCS. Based on discussion with forestry department officials, FCS data is normally about 20% lower from the actual volume because smaller end of diameter is used for its volume calculation.

Table 8.5 Comparison results by using data of Pekan FCS for 366 trees of *G. bancanus*

Model no.	Equation	Estimated volume (m^3)	Difference (%)
1	$V=-3.2905 + 0.1264(dbh)$	1777.7	18.5
2	$V=-0.9756 + 0.0369(dbh) + 0.0008(dbh^2)$	1751.3	16.8
3	$V = -0.0005 + 0.001(dbh^2)$	1547.1	3.2
4	$Ln(V)= -7.2213 + 2.1057\ Ln(dbh)$	1761.5	17.5
5	$V= 0.0013 * dbh^{1.9766}$	1823.6	21.6
6	$V= -1.1459 + 0.0437(dbh) + 0.0007(dbh^2)$	1694.7	13.0
7	$V= -0.0926 + 0.0012\ (dbh^2)$	1822.9	21.6
8	$V= -0.0455 + 0.0012\ (dbh^2)$	1840.1	22.7
9	$V=-1.0863 + 0.0412dbh + 0.0008\ (dbh^2)$	1812.2	20.8

8.4 CONCLUSIONS

The local volume table (LVT) developed for *G. bancanus* in Pekan FR was developed. The equation $Ln(V)= -7.2213 + 2.1057\ Ln(dbh)$, was selected as the best-fitted model based on the FI. The equation produced about 17.5% more timber volume compared with that of the FCS and is logically acceptable to be used to the estimate volume of *G. bancanus* trees in Pekan FR.

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TECHNICAL INFORMATION ON
OPTIMUM HARVESTING REGIMES OF PEAT SWAMP FORESTS IN PENINSULAR MALAYSIA

This book is one of the publications of the ITTO-CITES Project of FRIM activity. Although the main activities were conducted under the Levy Funding Grant provided by the Ministry of Plantation Industries and Commodities, Malaysia, a portion of the study and publication of this book was funded by the ITTO-CITES Project. There are eight chapters in this technical handbook starting from Project background, followed by Development of cutting options, Impact analyses of reduced impact logging (RIL), Determination of optimum harvesting, Financial evaluation, Productivity and time study of RIL, Hydrological response and ending with Development of a local volume table (LVT) for *Gonystylus bancanus* in Pekan Forest Reserve, Pahang. It is hoped that information provided in this book will be another important reference to improving the management and conservation of peat swamp forests in our country.