Generation of spatial distribution maps of *Gonystylus bancanus* (ramin) using hyperspectral technology and determination of sustainable level of harvest of ramin in production forests of Peninsular Malaysia

Technical Report Component 2 on Population Dynamics and Optimum Harvest of *Gonystylus bancanus* in Production Peat Swamp Forests of Peninsular Malaysia

ITTO-CITES Project Ensuring International Trade in CITES-listed Timber species is Consistent with their Sustainable Management and Conservation

Prepared by:
Ismail Parlan
Ismail Harun
Abd Rahman Kassim

Forestry & Environment Division, Forest Research Institute Malaysia (FRIM)

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Technical and scientific staff
Dr Ismail Parlan, Dr Ismail Harun, Dr Abd Rahman Kassim, Hashim Mohd & Harfendy Osman

Implementing Institutions
Forest Research Institute Malaysia (FRIM), 52109 Kepong, Selangor Darul Ehsan, Malaysia
Tel: 603-62797000 Fax: 603 62731314

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Ismail Parlan
Ismail Harun
Abd Rahman Kassim

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ABBREVIATIONS

BN	Bintangor
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DANIDA	Danish International Development Assistance
dbh	diameter at breast height
DM	Dipterocarps meranti
DNM	Dipterocarps non-meranti
FR	forest reserve
FRIM	Forest Research Institute Malaysia
GYMTPSF	Growth and Yield Model for Tropical Peat Swamp Forest
ha	hectare
ITTO	International Tropical Timber Organization
JTR	jalan tarik Rimbaka
m	meter
MAI	mean annual increment
NDHHW	Non-dipterocarps heavy hardwoods
NDLHW	Non-dipterocarps light hardwoods
NDMHW	Non-dipterocarps medium hardwoods
NDMICS	Non-dipterocarps misc.
PSF	peat swamp forest
RIL	reduced impact logging
RTH	Rimbaka timber harvester
SEPPSF	South East Pahang Peat Swamp Forest
SMS	selective management system
SPA	seed production area
UNDP	United Nations Development Program
VJR	virgin jungle reserve
yr	year

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SUMMARY

Currently, the peat swamp forests in Peninsular Malaysia are managed under a modified Selective Management System, which is a modification of a system designed for the management of the dry inland forests. As the peat swamp forest is a unique forest type with silvicultural characteristics that are rather different from that of the dry inland forests, it is hoped that through this project, suitable silvicultural and management practices could be further improved so that the peat swamp forests could be managed in a sustainable manner. This project is Component 2 of the main Activity of FRIM's ITTO-CITES Project entitled "Generation of spatial distribution maps of ramin (*Gonystylus bancanus*) using hyperspectral technology and determination of sustainable level of harvgest of ramin in production forests of Peninsular Malaysia". The general objective of Component 2 is to enhance conservation by determining sustainable level of harvest for *G. bancanus* in production forests of Peninsular Malaysia. Study site for this project was Pekan Forest Reserve, Pahang. This study focuses on two aspects on *G. bancanus*; habitat specialization and sustainable harvest. The habitat specialization is important to understand the population and ecology characteristics of this species. Meanwhile, 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. This study elaborates population and ecology characteristics of *G. bancanus* in Pekan FR based on stock classification; richly-, moderately- and poor- stocked of *G. bancanus* areas. The study also indicated that the volume mean annual increment for the whole stand in peat swamp forest is about 1.8 m^3ha^{-1} yr^{-1} for all trees equal and greater than 15 cm dbh. Medium and high cutting limits were found 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*.

1.0 INTRODUCTION

This is Component 2 for main project entitled "Generation of spatial distribution maps of ramin (*Gonystylus bancanus*) using hyperspectral technology and determination of sustainable level of harvest of ramin in production forests of Peninsular Malaysia". Main objective of Component 2 is to enhance conservation by determining sustainable level of harvest for *G. bancanus* in production forests of Peninsular Malaysia. The Component 1 of the main project is reported in separate Technical Report. The whole project duration is for 2 years (November 2008 – December 2010).

Since *G. bancanus* has been up-listed to Appendix II (CITES), the species is subjected to Non-detrimental Finding (NDF) report before they be traded internationally (Jumat 2004). In the preparation of NDF report, it is important to investigate the current stocking of the species and its population dynamics to enable exploitation of the species be carried out in a sustainable manner. In timber production forest, sustainable level of harvest can be determined by projecting future growth from the current stocking of both species in natural forest stands. Projection can be done manually or by preparing a computer simulation model to enable us to determine the most optimum sustainable level of harvest that does not jeopardize the species sustainability in the nature. This study focuses on two aspects on *G. bancanus*; natural habitat specialization and sustainable harvest.

The habitat specialization is important to understand the population and ecology characteristics of this species. Meanwhile, 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 is a modification of 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 that of the dry inland forests, it is hoped that through this study, suitable silvicultural and management practices could be further improved so that the PSF could be managed in a sustainable manner.

2.0 APPLIED METHODOLOGY

The study was conducted at Pekan FR in Southeast Pahang Peat Swamp Forest (SEPPSF) as shown in Figure 1. This is main study site of UNDP/GEF Peat Swamp Forest Project conducted in 2004 to 2007 (Jamlus *et al*. 2007).

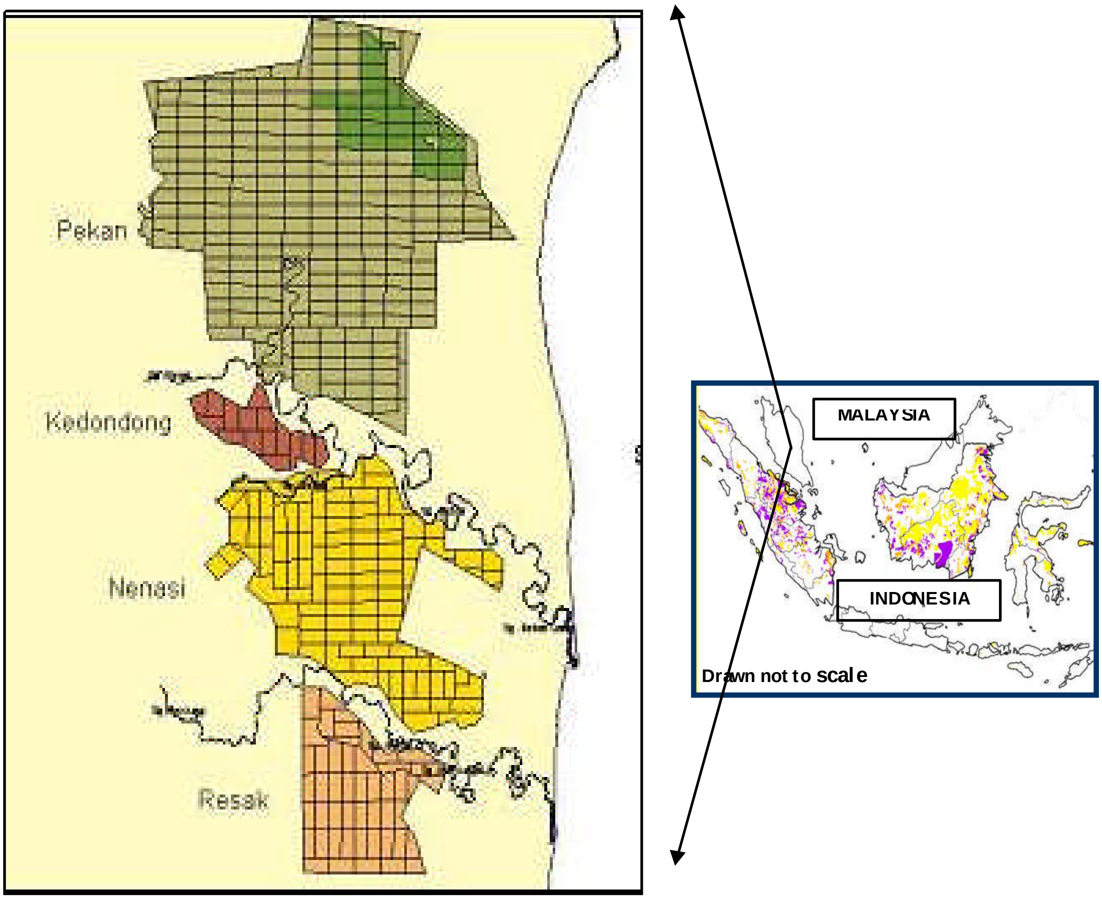
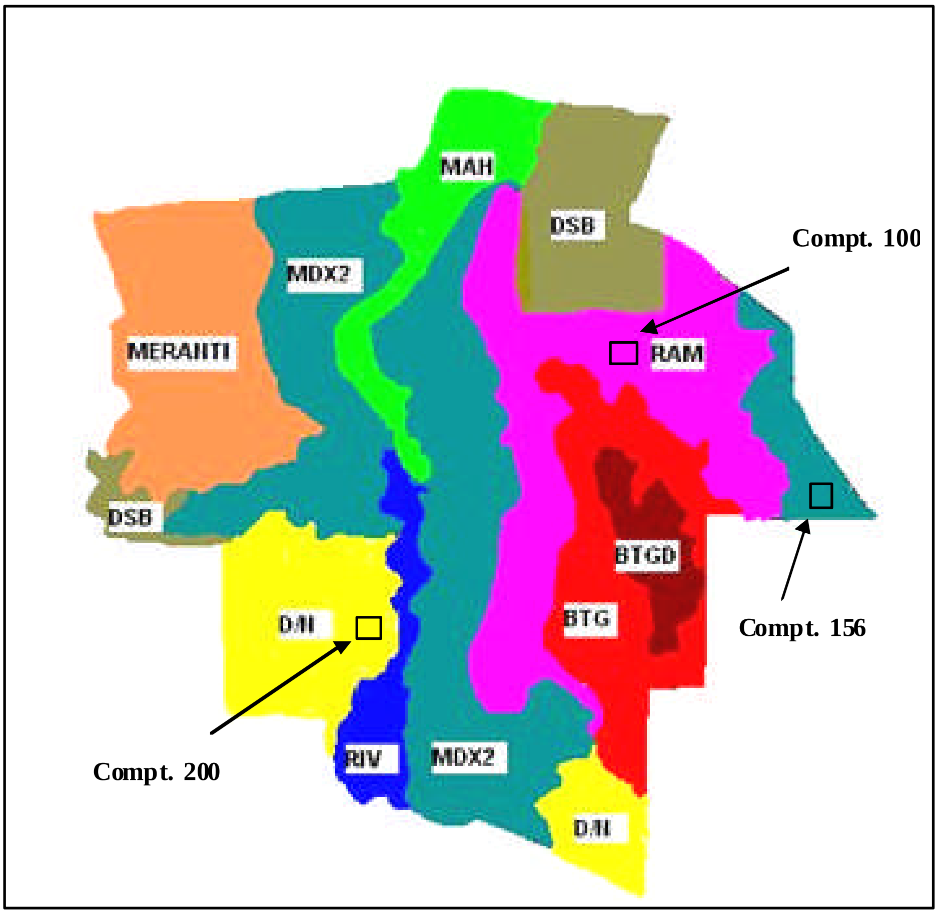


Figure 1 Location of Pekan FR in Southeast Pahang Peat Swamp Forest (SEPPSF)

2.1 Habitat Specialization

Forest subtypes in the Pekan FR that classified by Blackett and Wollesen (2005) and later refined by UNDP/GEF (2006) were used as the basis in selecting suitable study sites. In order to study the natural distribution of *G. bancanus*, the study sites should represent areas of richly-, moderately- and poorly-stocked *G. bancanus*. Thus, Ramin-Bintangor, Kempas-Ramin-Durian and Durian-Nyatoh subtypes were selected as study sites for richly-, moderately- and poorly-stocked *G. bancanus* areas, respectively (Figure 2).



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

A one-hectare plot of 100 x 100 m each was established in Compartments 100, 156 and 200 at Pekan FR. All of the plots in each study site were divided into twenty-five, 20 x 20 m contiguous subplots. In the subplots of 20 x 20 m, all trees and poles with dbh of 10 cm and above were measured, identified up to species level, tagged and mapped. As for soil analyses, soil samples from nine subplots were selected systematically. Three topsoil samples (0 – 20 cm depth) were taken randomly in the selected subplots and the three samples were then bulked together to represent soil sample for the respective subplots. The soil samples were brought to the soil laboratory for analyses of physical and chemical properties. Peat depth was measured using soil depth auger bar. The auger bar is a combination of several iron bars with a meter length each.

All trees were identified, recorded, tagged and its coordinates were mapped on a graph paper. The coordinates were then transferred to the tree distribution map in the computer based on the coordinates on the ground. Tree distribution analyses were then carried out using Morisita's Index (I_d) of Dispersion. If the dispersion is random, then $I_d = 1.0$, if perfectly uniform, $I_d = 0$, and if maximally aggregated, $I_d = n$ (number of plots). Several indices such as Importance Value Index (IV_i), Shannon-Weiner Diversity Index (H') and Margalef's Diversity Index (D_{mg}) were also calculated to determine species importance and species diversity of the plots, respectively.

Tree biomass is defined as the total amount of living organic matter in trees and is expressed as oven-dry biomass per unit area usually in tonnes ha^{-1} (Brown 1997). In this study, equations by Istomo (2006) are more appropriate due to the similarity in forest type as follows:

$$\text{Above-ground biomass} = 0.0145\,(dbh^3) - 0.4659\,(dbh^2) + 30.64\,(dbh) - 263.32 \quad \text{(note: dbh in cm)}$$

Below-ground biomass = 20.1% of Above-ground biomass

Total tree biomass = Above-ground biomass + Below-ground biomass

2.2 Sustainable Harvest

In projecting the sustainable harvest, this study was undertaken in three major parts as the following:

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 FR (Figure 3). 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 1. The amounts of timber removed from the original forest are as shown in Figure 4.

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.

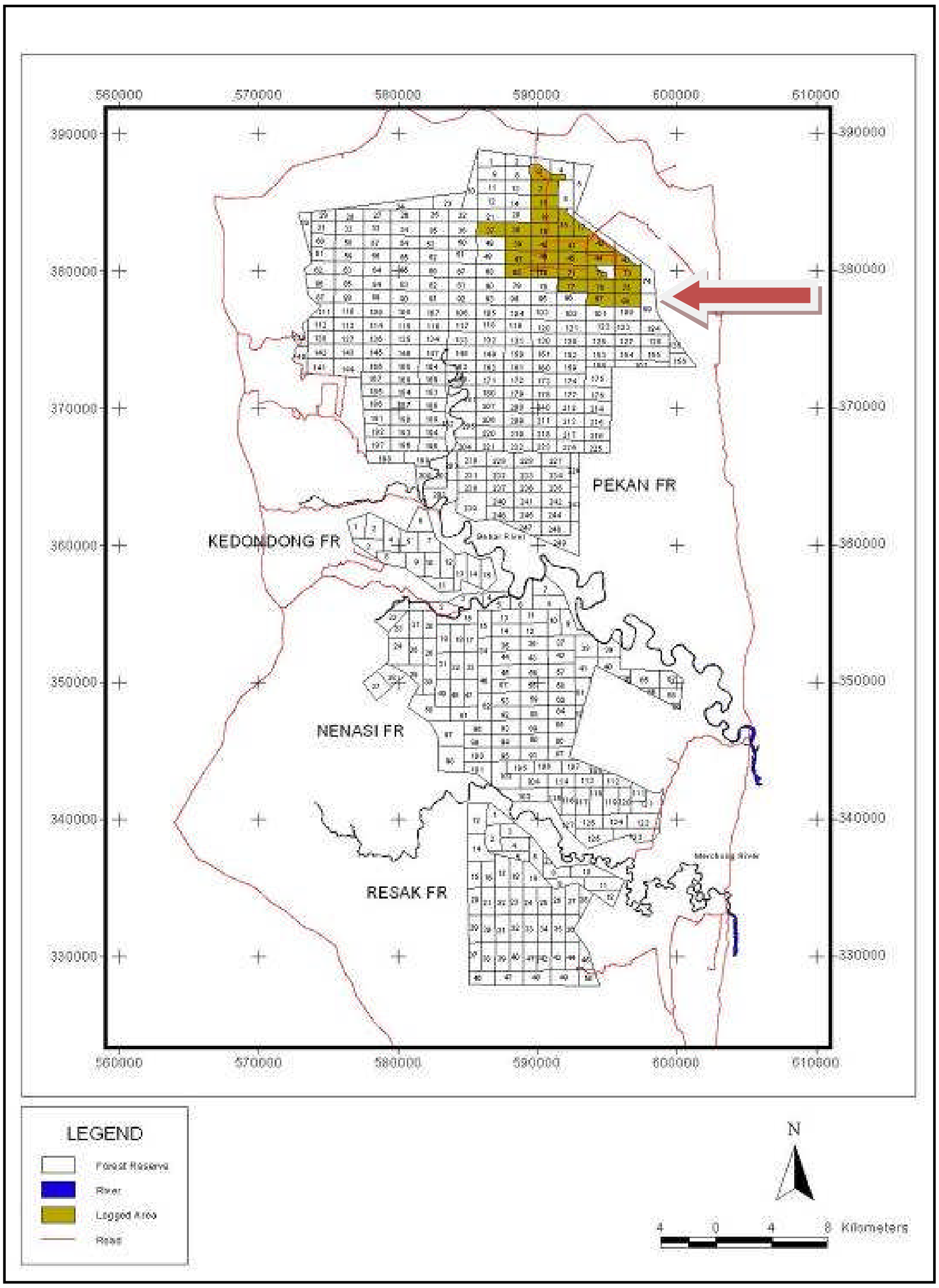


Figure 3 Location of the study area in Compartment 99, Pekan FR, Pahang

Table 1 Plot treatments at Compartment 99, Pekan FR

Treatment	Abbreviation
High cutting intensity (cut all trees 30 cm dbh and larger) – 36%	T1
Medium cutting intensity (cut all trees 45 cm dbh and larger) – 20%	T2
Low cutting intensity (cut 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

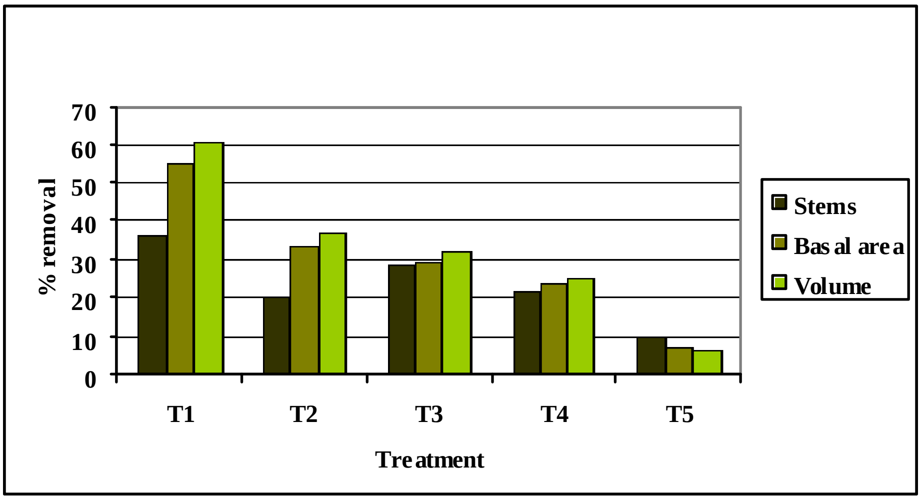


Figure 4 The percent of removal from the plots

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.

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). The study area of 100 ha was divided to four blocks that assigned with different cutting limits as described in Table 2 and Figure 5.

Table 2 Selected cutting limits for species group in each harvesting block

Block	**Cutting limits (dbh)**	**Description**
	Group 1 – 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 = Bintangor spp. only
Group 3 = other species

The cutting limits were tested on the ground using Rimbaka timber harvester (RTH). 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 6). 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 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 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 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).

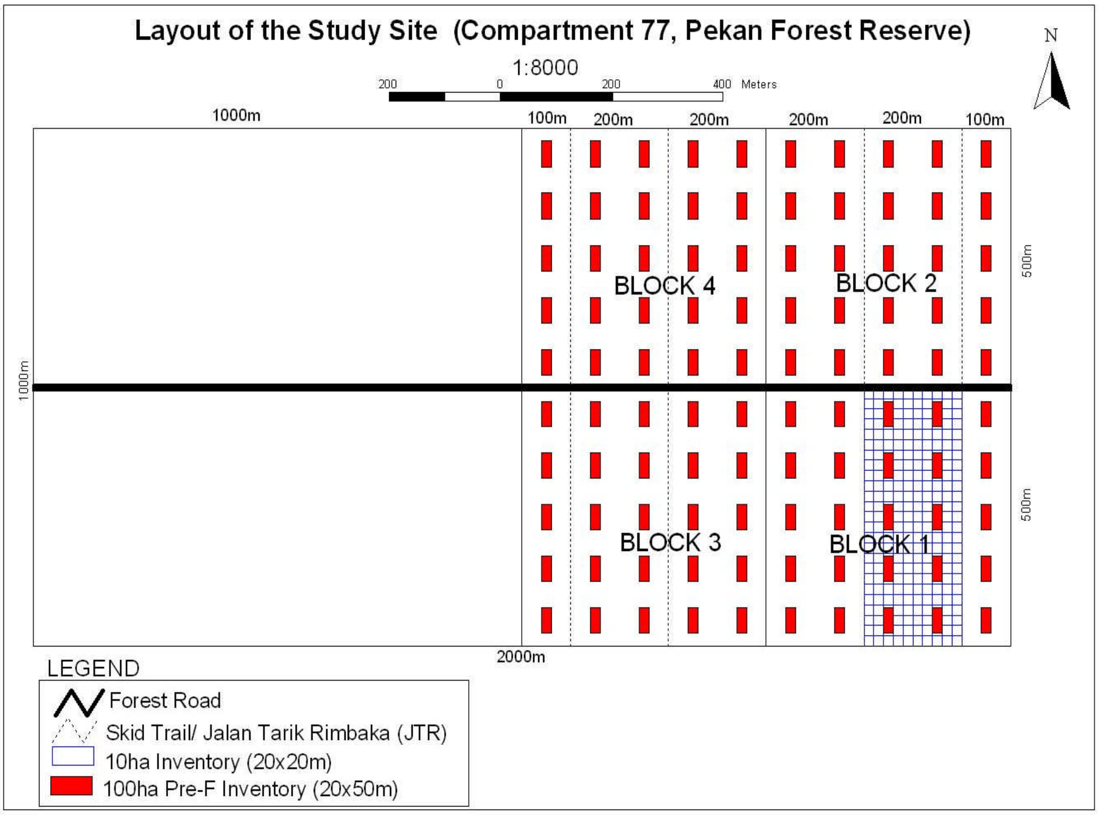


Figure 5 Study site of FRIM's plot at Compartment 77, Pekan FR

Figure 6 The Rimbaka timber harvester restricts its movement by pulling logs using a long cable hence minimizing the extraction damage to the forest floor

3.0 ANALYSIS AND INTERPRETATION OF THE DATA AND RESULTS

3.1 Habitat Specialization

Taxonomic composition

Number of taxa of trees with dbh of 10 cm and above in plots at Compartments 100, 156 and 200 are shown in Table 3. As for example, a total of 376 trees were enumerated in the plot at Compartment 100 which comprised of 49 species in 38 genera and 25 families. Nonetheless, Compartment 200 has most numbers in terms of tree species, genus and family.

Table 3 Number of taxa at the plots in Compartments 100, 156 and 200, Pekan FR

Plot	Species	Genus	Family
Compartment 100	49	38	25
Compartment 156	68	49	28
Compartment 200	100	76	38

Abundance

Table 4 shows tree stockings of various dbh classes in the plots in Compartments 100, 156 and 200 at Pekan FR. In general, number of trees decline with increase of dbh sizes, whereby trees with dbh of 55.0 cm and above were less in number compared with those of lower dbh classes. The stand structures differed from one plot to another, however, the patterns are similar of inverse J shape. It shows that trees with 10.0 – 24.9 cm dbh represented the most number with more than 50% in each plot, and even about 77% for the plot in Compartment 200.

Table 4 Tree stockings in the plots at Compartments 100, 156 and 200, Pekan FR

Dbh class (cm)	Compartment 100 (stems ha^{-1})	Compartment 156 (stems ha^{-1})	Compartment 200 (stems ha^{-1})
10.0 – 24.9	182 (48.4%)	358 (64.3%)	425 (76.6%)
25.0 – 39.9	84 (22.3%)	138 (24.8%)	84 (15.1%)
40.0 – 54.9	73 (19.4%)	41 (7.4%)	32 (5.8%)
55.0 – 69.9	34 (9.1%)	14 (2.5%)	5 (0.9%)
≥ 70.0	3 (0.8%)	6 (1.1%)	9 (1.6%)
Total	376 (100%)	557 (100%)	555 (100%)

Table 5 shows *G. bancanus* stockings in the plots of Compartments 100, 156 and 200, Pekan FR. There were 25, 5 and 3 stands of *G. bancanus* with dbh of 10 cm and above in the plots in Compartments 100, 156 and 200, respectively.

Table 5 Stockings of *G. bancanus* in the plots of Compartments 100, 156 and 200, Pekan FR

Dbh class (cm)	**Compartment 100 (stems ha^{-1})**	**Compartment 156 (stems ha^{-1})**	**Compartment 200 (stems ha^{-1})**
10.0 – 24.9	1	2	1
25.0 – 39.9	2	0	1
40.0 – 54.9	11	0	0
55.0 – 69.9	11	2	1
$\geq$ 70.0	0	1	0
Total	25	5	3

Tree basal area of various dbh classes at the plots in Compartments 100, 156 and 200, Pekan FR are shown in Table 6. The total basal area for the plots in Compartments 100, 156 and 200 were estimated at 35.04, 33.44 and 26.54 m^2 ha^{-1}, respectively. Dbh class that has the largest basal area were varied; it was dbh class of 40.0 – 54.9 cm for plot in Compartment 100 with 13.11 m^2, dbh class of 25.0 – 39.9 cm for Compartment 156 with 10.36 m^2 ha^{-1} and dbh class of 10.0 – 24.9 cm for Compartment 200 with 7.84 m^2 ha^{-1}.

Table 6 Basal area of all species in the plots in Compartments 100, 156 and 200, Pekan FR

Dbh class (cm)	**Compartment 100 (m^2 ha^{-1})**	**Compartment 156 (m^2 ha^{-1})**	**Compartment 200 (m^2 ha^{-1})**
10.0 – 24.9	3.93 (11.2%)	7.56 (22.6%)	7.84 (29.5%)
25.0 – 39.9	6.94 (19.8%)	10.36 (31.0%)	6.15 (23.2%)
40.0 – 54.9	13.11 (37.4%)	7.27 (21.7%)	5.30 (20.0%)
55.0 – 69.9	9.83 (28.1%)	3.91 (11.7%)	1.52 (5.7%)
$\geq$ 70.0	1.23 (3.5%)	4.34 (13.0%)	5.73 (21.6%)
Total	35.04 (100%)	33.44 (100%)	26.54 (100%)

The basal area for *G. bancanus* in the plots at Compartments 100, 156 and 200, Pekan FR are given in Table 7. The total basal area of *G. bancanus* for the plots in Compartments 100, 156 and 200 were 5.57, 1.22 and 0.37 m^2 ha^{-1}, respectively. The highest basal area for *G. bancanus* in all plots was recorded in dbh class of 55.0 – 69.9 cm.

Table 7 Basal areas of *G. bancanus* in the plots at Compartments 100, 156 and 200, Pekan FR

Dbh class (cm)	**Compartment 100 (m^2 ha^{-1})**	**Compartment 156 (m^2 ha^{-1})**	**Compartment 200 (m^2 ha^{-1})**
10.0 – 24.9	0.04	0.08	0.01
25.0 – 39.9	0.10	0	0.09
40.0 – 54.9	2.11	0	0
55.0 – 69.9	3.32	0.64	0.27
≥ 70.0	0	0.50	0
Total	5.57	1.22	0.37

Table 8 shows the standing tree volumes in the plots at Compartments 100, 156 and 200, Pekan FR. The total volumes for the plots in Compartments 100, 156 and 200 were 325.83, 290.33 and 265.54 m^3 ha^{-1}, respectively. Dbh class with the highest volume for the plot in Compartment 100 was 40.0 – 54.9 cm with 136.49 m^3 ha^{-1}, while in Compartments 156 and 200, dbh classes of 25.0 – 39.9 cm and ≥ 70.0 cm showed the highest volume of 80.68 and 80.75 m^3 ha^{-1}, respectively.

Table 8 Estimated standing volumes of trees in the plots at Compartments 100, 156 and 200, Pekan FR

Dbh class (cm)	**Compartment 100 (m^3 ha^{-1})**	**Compartment 156 (m^3 ha^{-1})**	**Compartment 200 (m^3 ha^{-1})**
10.0 – 24.9	20.44 (6.3%)	40.79 (14.0%)	45.25 (17.0%)
25.0 – 39.9	65.17 (20.0%)	80.68 (27.8%)	55.84 (21.0%)
40.0 – 54.9	136.49 (41.9%)	74.29 (25.6%)	68.57 (25.8%)
55.0 – 69.9	92.97 (28.5%)	41.28 (14.2%)	15.13 (5.7%)
≥ 70.0	10.76 (3.3%)	53.29 (18.4%)	80.75 (30.4%)
Total	325.83 (100%)	290.33 (100%)	265.54 (100%)

Table 9 presents the standing tree volumes in the plots in Compartments 100, 156 and 200, Pekan FR for *G. bancanus*. The total volumes of *G. bancanus* for the plots in Compartments 100, 156 and 200 were 72.40, 18.86 and 5.26 m^3 ha^{-1}, respectively. Dbh class of 40.0 – 54.9 cm showed the highest volume for the plot at Compartment 100 with volume of 45.90 m^3 ha^{-1}, while for the plot in Compartment 156 the dbh class was ≥ 70.0 cm with 9.85 m^3 ha^{-1}, and for the plot in Compartment 200 the dbh class was 55.0 – 69.9 cm with 3.80 m^3 ha^{-1}.

Table 9 Estimated standing volumes of *G. bancanus* in the plots in Compartments 100, 156 and 200, Pekan FR

Dbh class (cm)	Compartment 100 (m^3 ha^{-1})	Compartment 156 (m^3 ha^{-1})	Compartment 200 (m^3 ha^{-1})
10.0 – 24.9	0.30	0.42	0.09
25.0 – 39.9	0.89	0	1.37
40.0 – 54.9	25.31	0	0
55.0 – 69.9	45.90	8.59	3.80
$\geq$ 70.0	0	9.85	0
Total	72.40	18.86	5.26

Tree distribution

Results of the Morisita's Index (I_d) of Dispersion for all species (including *G. bancanus*) and *G. bancanus* in particular are shown in Table 10. The I_d values show that all trees in all plots were distributed randomly. As for *G. bancanus*, it is randomly distributed in plot at Compartment 100, but significantly distributed uniformly in plots of Compartments 156 and 200.The distribution of trees with dbh of 10 cm and above in the one-hectare plots in Compartments 100, 156 and 200 are shown in Figures 7 – 9.

Table 10 Morisita's Index (I_d) of Dispersion values for all species and specifically for *G. bancanus*

Plot	Morisita's Index (I_d)	$\chi^2_{computed}$	χ^2_{table}	Dispersion
Compartment 100				
All species	0.97	14.0	421.2	random ^{ns}
G. bancanus	0.67	16.0	36.4	random ^{ns}
Compartment 156				
All species	1.06	55.1	611.9	random ^{ns}
G. bancanus	0.00	20.0	9.5	uniform *
Compartment 200				
All species	1.01	27.3	609.9	random ^{ns}
G. bancanus	0.00	22.0	5.9	uniform *

Notes: ^{ns} = not significant at $P < 0.05$, * = significant at $P < 0.05$

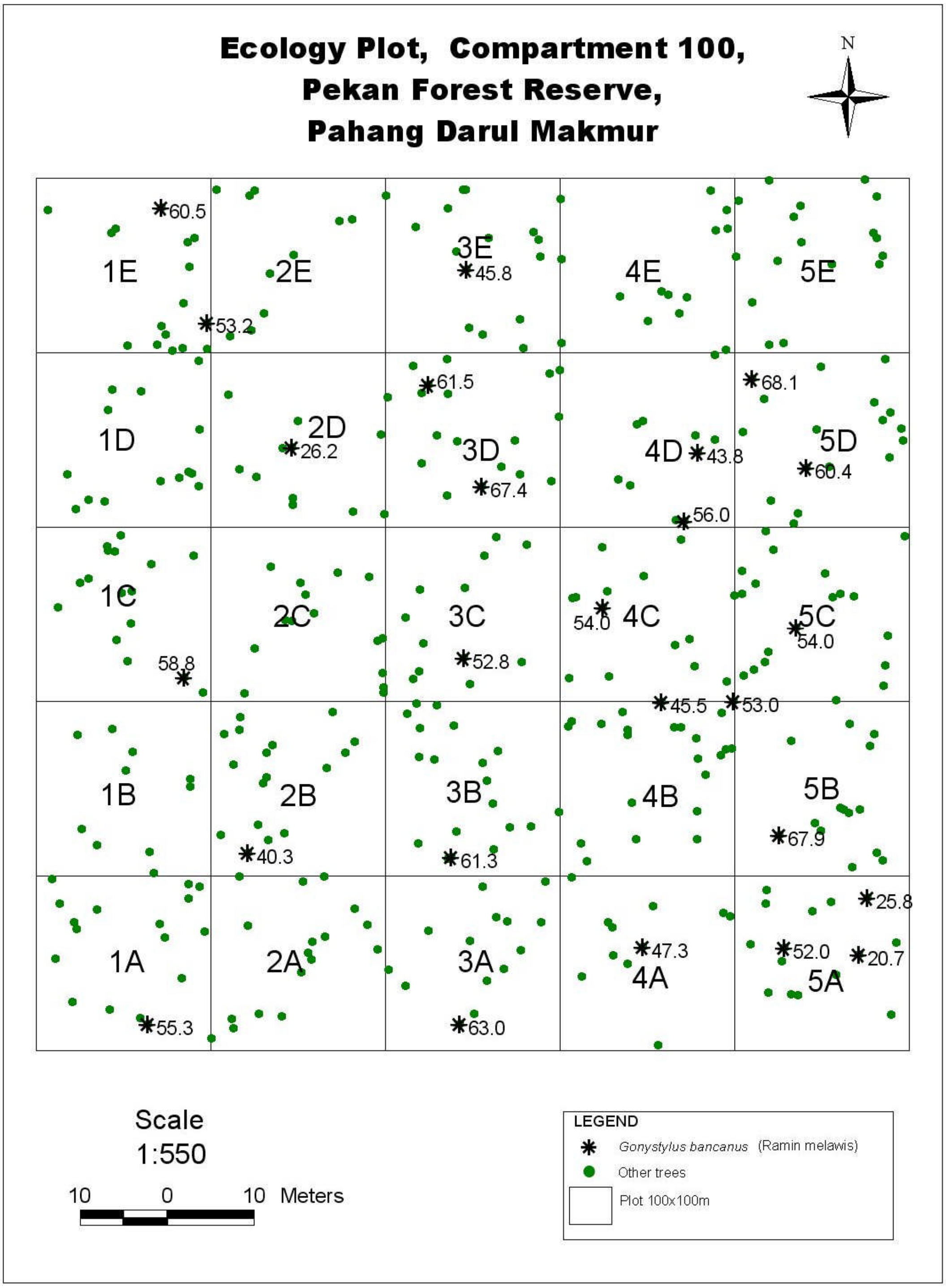


Figure 7 Distribution of all trees and *G. bancanus* (n = 25) (10 cm dbh and above) in one-hectare plot of Compartment 100, Pekan FR

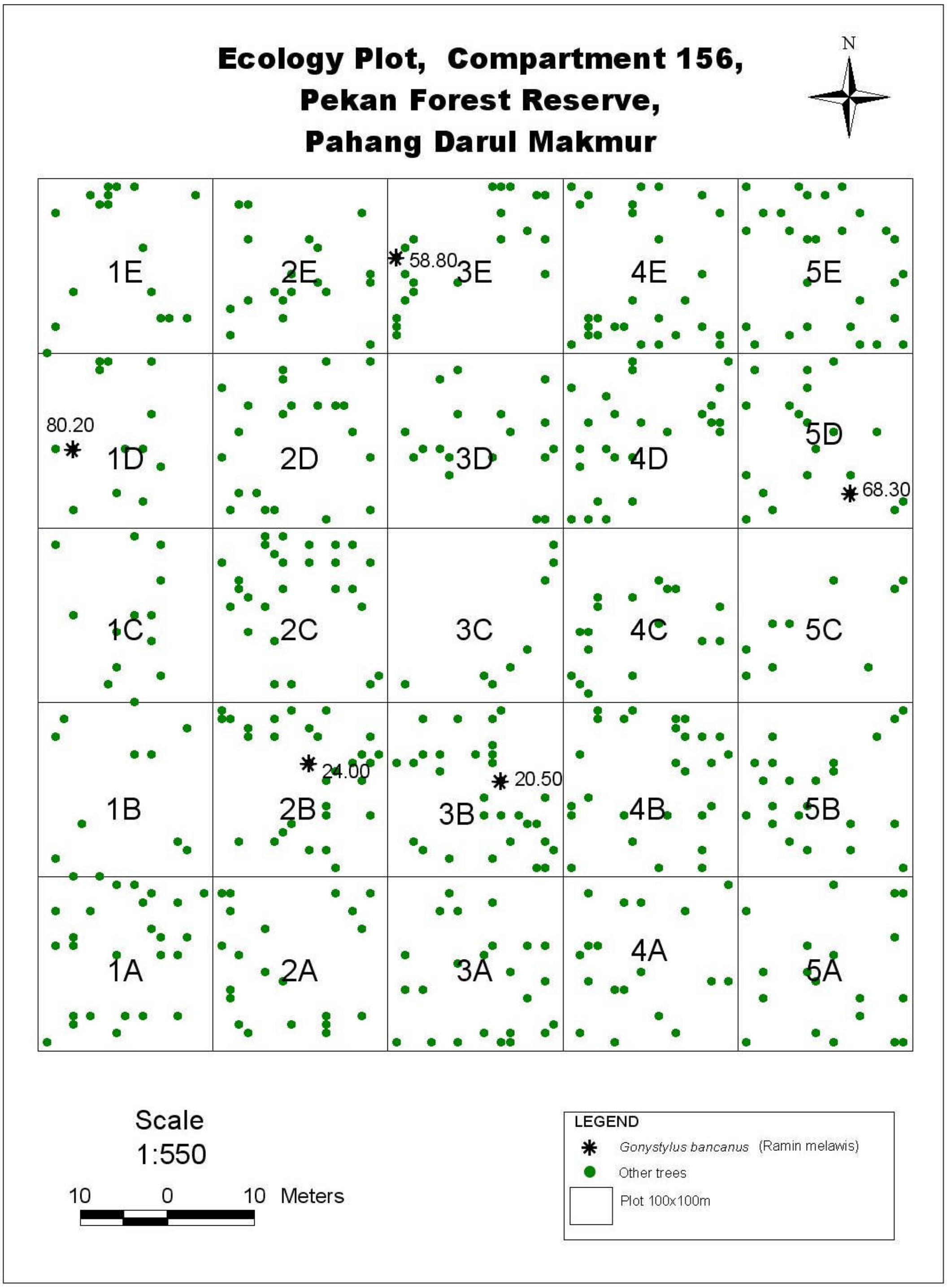


Figure 8 Distribution of all trees and *G. bancanus* (n = 5) (10 cm dbh and above in one-hectare plot of Compartment 156, Pekan FR

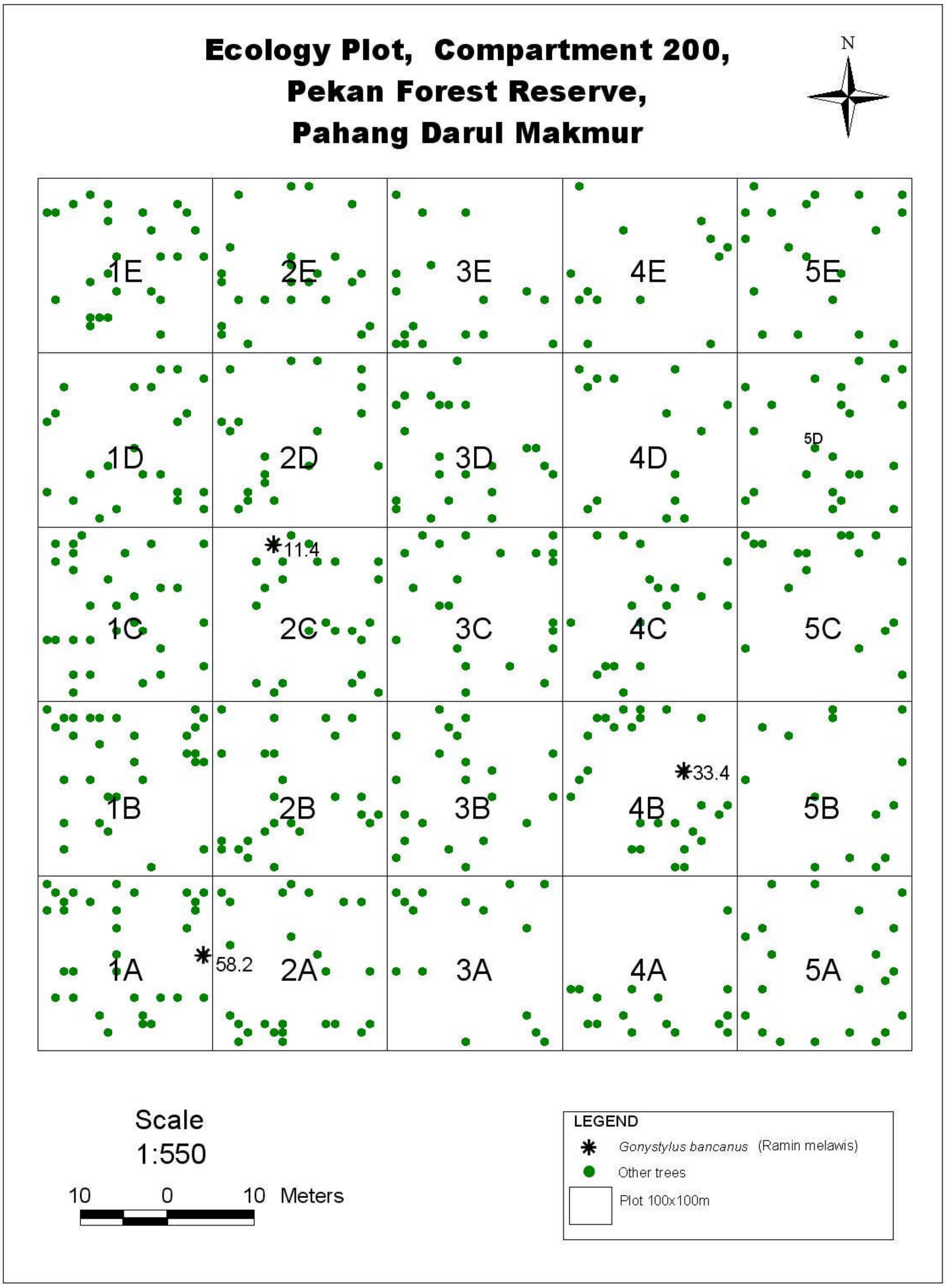


Figure 9 Distribution of all trees and *G. bancanus* (n = 3) (10 cm dbh and above in one-hectare plot of Compartment 200 of Pekan FR

Importance value index (IV_i)

In Compartment 100, the three most dominant species were *C. ferrugineum var. ferrugineum* with IV_i of 22.23%, followed by *G. bancanus* with IV_i of 9.88% and *Koompassia malaccensis* with IV_i of 5.87%. The IV_i of the *C. ferrugineum var. ferrugineum*, which is species at first rank in the list was huge compared with all other species due to its high relative density and relative frequency.

In the plot at Compartment 156, the three most dominant species were *Stemonurus secundiflorus* with IV_i of 7.22%, followed by *Gymnacranthera farquhariana var. eugeniifolia* with IV_i of 7.08% and *Blumeodendron tokbrai* with IV_i of 5.72%. In this plot, *G. bancanus* is ranked at number 14 with IV_i of 1.98%. Meanwhile, the three most dominant species based on IV_i in the plot at Compartment 200 were *Madhuca motleyana* with IV_i of 5.88%, *Santiria laevigata* with IV_i of 5.58% and *Garcinia nigrolineata* with IV_i of 3.54%. In this plot, *G. bancanus* was ranked at number 38 with IV_i of 0.87%.

Species diversity

The diversity of tree species in the study plots calculated using the Shannon-Weiner Diversity Index (H') show values of 3.15 (H'_{max} = 3.89), 3.61 (H'_{max} = 4.25) and 4.12 (H'_{max} = 4.63) for the plots in Compartments 100, 156 and 200, respectively (Table 11). The diversity of the plot in Compartment 200 was significantly higher ($P < 0.05$) than the values of Compartments 156 and 100, similarly for the plot in Compartment 156 compared with that in Compartment 100. Based on Margalef's Diversity Index (D_{mg}), plots at Compartments 100, 156 and 200, Pekan FR had D_{mg} value of 18.64, 24.40 and 36.07, respectively. It further confirmed the higher diversity in plot at Compartment 200 as their number of species was the highest.

Table 11 Summary on diversity indices in the study plots at Pekan FR

Plot	Compartment 100	Compartment 156	Compartment 200
Shannon-Weiner Diversity Index (H')	3.15 [a]	3.61 [b]	4.12 [c]
Evenness	0.81	0.85	0.89
H'_{max}	3.89	4.25	4.63
Margalef's Diversity Index (D_{mg})	18.64	24.40	36.07

Note: different letter(s) denote significant difference at $P < 0.05$

Tree biomass

Total biomass of trees with dbh of 10 cm and above in the one-hectare plots at Compartments 100, 156 and 200 are shown in Table 12. The plot in Compartment 100 gave the highest total tree biomass value of 414.57 tonnes ha^{-1}, followed by the plots in Compartment 156 with 346.36 tonnes ha^{-1} and Compartment 200 of 330.61 tonnes ha^{-1}.

Tree with dbh class of 40.0 – 54.9 cm in the plot in Compartment 100 indicated the highest total tree biomass of 153. 22 tonnes ha^{-1} and the lowest was dbh class of $\geq$ 70.0 cm with 18.26 tonnes ha^{-1}. The dbh classes of 25.0 – 39.9 cm and 55.0 – 69.9 cm were the highest and lowest dbh classes with 112.13 and 50.47 tonnes ha^{-1}, respectively for the plot in Compartment 156. As for the plot in Compartment 200, the highest total tree biomass was in the dbh class of $\geq$ 70.0 cm with 111.45 tonnes ha^{-1} and the lowest was the dbh class of 55.0 – 69.9 cm with 20.35 tonnes ha^{-1}.

Table 12 Biomass of trees in the plots at Compartments 100, 156 and 200, Pekan FR

Dbh class (cm)	Compartment 100 (t ha^{-1})	Compartment 156 (t ha^{-1})	Compartment 200 (t ha^{-1})
10.0 – 24.9	38.85	74.75	73.47
25.0 – 39.9	75.27	112.13	64.38
40.0 – 54.9	153.22	84.41	60.95
55.0 – 69.9	128.96	50.47	20.35
$\geq$ 70.0	18.26	80.44	111.45
Total	414.57	346.36	330.61

In Compartment 100, the three species that had the highest tree biomass were *C. ferrugineum* var. *ferrugineum*, *G. bancanus* and *Tetramerista glabra* with 119.07, 58.46 and 30.78 tonnes ha^{-1}, respectively. In the plot at Compartment 156, three species with the highest tree biomass were *D. carinatus* with 25.23 tonnes ha^{-1} followed by *Litsea grandis* and *L. resinosa* with 21.52 and 20.90 tonnes ha^{-1}, respectively. Meanwhile, the three species with the highest tree biomass in plot at Compartment 200 were *K. malaccensis*, *M. motleyana* and *Santiria laevigata* with biomass estimations of 47.77, 20.78 and 15.72 tonnes ha^{-1}, respectively.

Table 13 shows the biomass estimation of *G. bancanus* in the one-hectare plot at Compartments 100, 156 and 200. Obviously, the plot at Compartment 100 gave the highest biomass of *G. bancanus* amounting to 58.46 tonnes ha^{-1} (14.1% of total tree biomass) followed by plot at the Compartment 156 of 17.45 tonnes ha^{-1} (4.9%) and the Compartment 200 of the lowest with an estimation of 4.36 tonnes ha^{-1} (1.3%). Overall, dbh class of 55.0 – 69.9 cm indicated the largest biomass for *G. bancanus* in all plots with values of 36.50, 8.59 and 3.36 tonnes ha^{-1} for Compartments 100, 156 and 200, respectively.

Table 13 Total biomass values for *G. bancanus* in the plots in Compartments 100, 156 and 200, Pekan FR

Dbh class (cm)	Compartment 100 (tonnes ha^{-1})	Compartment 156 (tonnes ha^{-1})	Compartment 200 (tonnes ha^{-1})
10.0 – 24.9	0.30	0.84	0.06
25.0 – 39.9	0.95	0.00	0.94
40.0 – 54.9	20.71	0.00	0.00
55.0 – 69.9	36.50	8.59	3.36
$\geq$ 70.0	0.00	8.02	0.00
Total	58.46	17.45	4.36

Soil physical and chemical properties

A summary of the soil properties taken in the nine selected subplots in each plot at the different compartments are shown in Table 14. The total cation exchange capacity (CEC) is the combination of cations Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, H^{+} and Al^{3+}, while the total inorganic-N is the combination of ammonia-N with nitrate-N. Based on texture classification for organic mineral and peat soils, the soil texture in Compartments 100 and 156 is peat (more than 50% organic matter) in contrast to that in Compartment 200 which is silty clay (58% silt, 42% clay and 0.4% sand).

In general, Compartment 100 followed by Compartment 156 had larger values of all parameters compared with Compartment 200 except for total CEC, available K, silt, clay and sand contents. In fact, silt, clay and sand contents in Compartments 100 and 156 were considered as zero because they were not detectable in the soil physical properties as their organic matter content was very high.

It was found that peat depth plays an important role in the natural distribution of *G. bancanus* in its habitat, as shown in Figure 10, which shows that only a few stands of *G. bancanus* were found in shallow peat of about 2 – 3 m depth, but more were found in deeper peat with more than 6 m depth.

Table 14 Summary of soil parameters in the plots in Compartments 100, 156 and 200, Pekan FR

Parameter	Compartment 100 mean ± s.e.	Compartment 156 mean ± s.e.	Compartment 200 mean ± s.e.
Peat depth (m)	[a] 7.00 ± 0.07	[b] 3.54 ± 0.16	[c] 1.29 ± 0.12
pH (in lab)	[a] 3.18 ± 0.03	[b] 3.02 ± 0.04	[c] 3.31 ± 0.03
Ca^{2+} (meq/100g)	[a] 1.40 ± 0.30	[b] 0.61 ± 0.07	[a] 0.69 ± 0.19
Mg^{2+} (meq/100g)	[a] 2.17 ± 0.11	[b] 1.16 ± 0.09	[c] 0.35 ± 0.03
Na^{+} (meq/100g)	[a] 0.34 ±0.02	[a] 0.30 ± 0.02	[b] 0.22 ± 0.01
K^{+} (meq/100g)	[a] 0.33 ± 0.05	[b] 0.15 ± 0.02	[a] 0.27 ± 0.01
H^{+} (meq/100g)	[a] 1.42 ± 0.11	[b] 1.77 ± 0.08	[a] 1.59 ± 0.09
Al^{3+} (meq/100g)	[a] 1.80 ± 0.28	[a] 3.06 ± 0.20	[c] 7.71 ± 0.41
Total cation exchange capacity (CEC) (meq/100g)	[a] 7.46 ± 0.41	[b] 7.05 ± 0.29	[a] 10.83 ± 0.47
Available Mg (µg/g)	[a] 264.10 ± 9.41	[b] 144.34 ± 10.41	[c] 45.83 ± 2.20
Available K (µg/g)	[a] 68.96 ± 13.27	[a] 57.04 ± 8.24	[c] 90.21 ± 5.32
Available P (µg/g)	[a] 32.42 ± 2.42	[b] 22.12 ± 0.48	[c] 2.05 ± 0.22
Ammonia-N (µg/g)	[a] 60.83 ± 4.25	[b] 43.67 ± 4.09	[a] 29.33 ± 2.07
Nitrate-N (µg/g)	[a] 63.33 ± 4.60	[a] 57.78 ± 3.45	[a] 60.56 ± 6.93
Total inorganic-N (µg/g)	[a] 124.17 ± 7.46	[ab] 101.44 ± 4.56	[ab] 89.89 ± 7.55
Silt (%)	0.00	0.00	57.67 ± 1.95
Clay (%)	0.00	0.00	41.92 ± 1.95
Sand (%)	0.00	0.00	0.42 ± 0.03
Organic matter (%)	[a] 97.90 ± 0.23	[b] 91.33 ± 0.79	[c] 14.32 ± 2.22
Soil texture	peat	peat	silty clay

Note: different letter(s) denote significant difference at $P < 0.05$

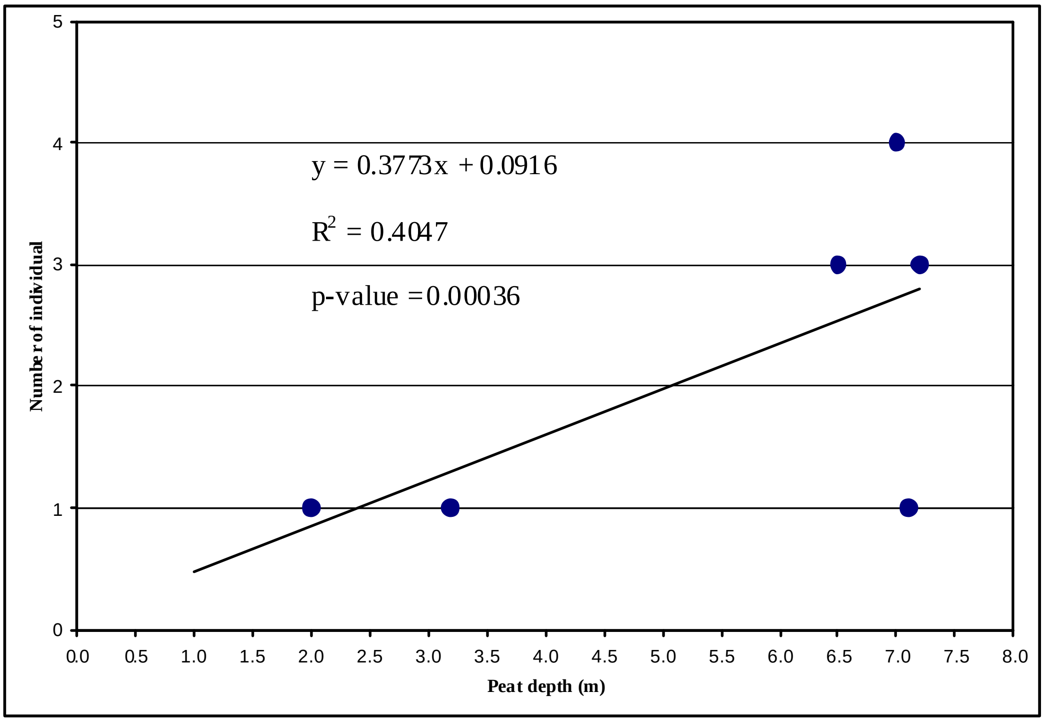


Figure 10 Relationship between peat depth and *G. bancanus* distribution. Note: there were 13 individuals of *G. bancanus* in the 27 selected subplots in all plots at Compartments 100, 156 and 200.

3.2 Sustainable Harvest

i) Data and results from Compartment 99, Pekan FR

Results indicated that the overall diameter growth of trees in PSF including *G. bancanus* is slower than other inland species. *G. bancanus* recorded the diameter growth of 0.28 to 0.51 cm yr^{-1} depending on the total basal area. The average mortality and ingrowth was recorded at about 2% per year. The statistic of the diameter increment is shown in Table 15.

Table 15 Diameter increment 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 and as shown as in Table 16. Diameter increment function for *G. bancanus* over total basal area is shown in Figure 11. The species recorded the average diameter increment of 0.28 to 0.51 cm yr^{-1}.

Table 16 Diameter increment functions for all species group in PSF

Species Group	Diameter increment functions
1. Dipterocarps Meranti (DM)	$D_i = \exp^{(-0.15539-0.011392*TBA)} - 0.2$
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)	$D_i = \exp^{(-0.25867-0.01475217*TBA)} - 0.2$

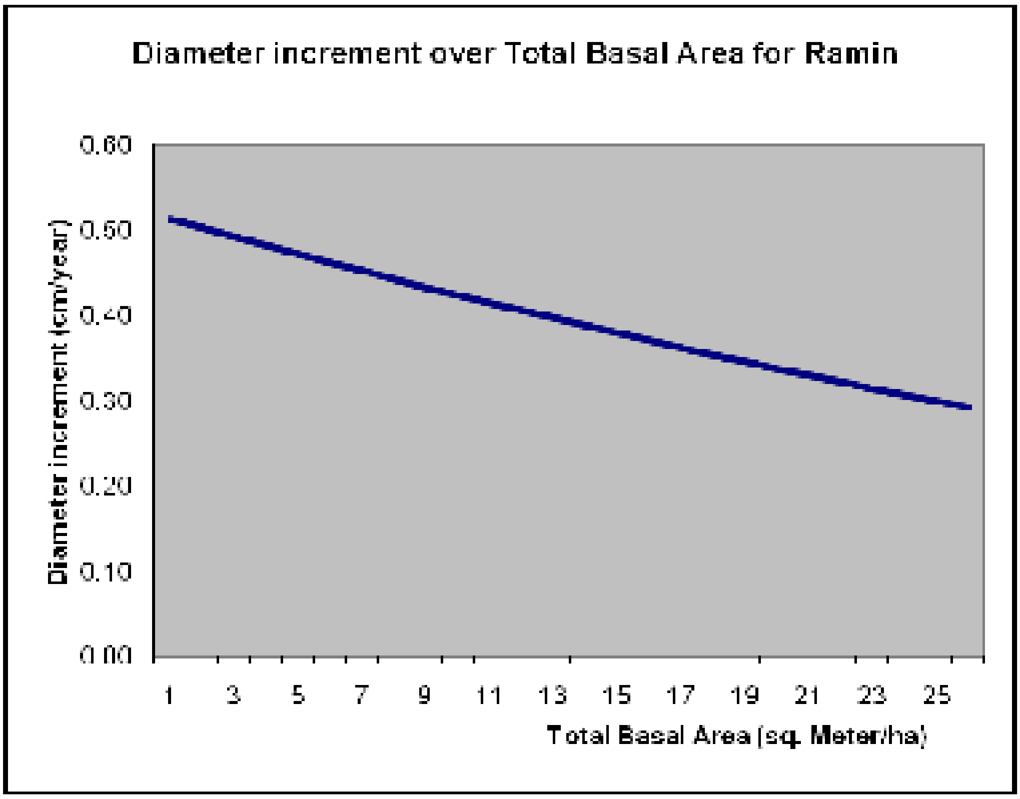


Figure 11 Diameter increment function for *G. bancanus*

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 greater than 15 cm dbh (Table 17). Result also indicated that medium and high cutting limits produce better future growth response especially for Block 3: 60/50/45 and Block 4: 65/55/50.

Table 17 Mean annual volume increment 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

ii) Data and results from Compartment 77, Pekan FR

Size structure (stand, basal area & volume per ha)

The stand structure (stem per ha^{-1}) form a reverse J-shape curve indicating that the smaller trees dominating he stand in terms of number of stems (Figure 12). On the other hand the size distribution of the basal area and volume indicate that the mid size of 45-60 cm dbh showed the highest stocking density. The pattern indicates that most of the growing space in the area is occupied by the middle size trees.

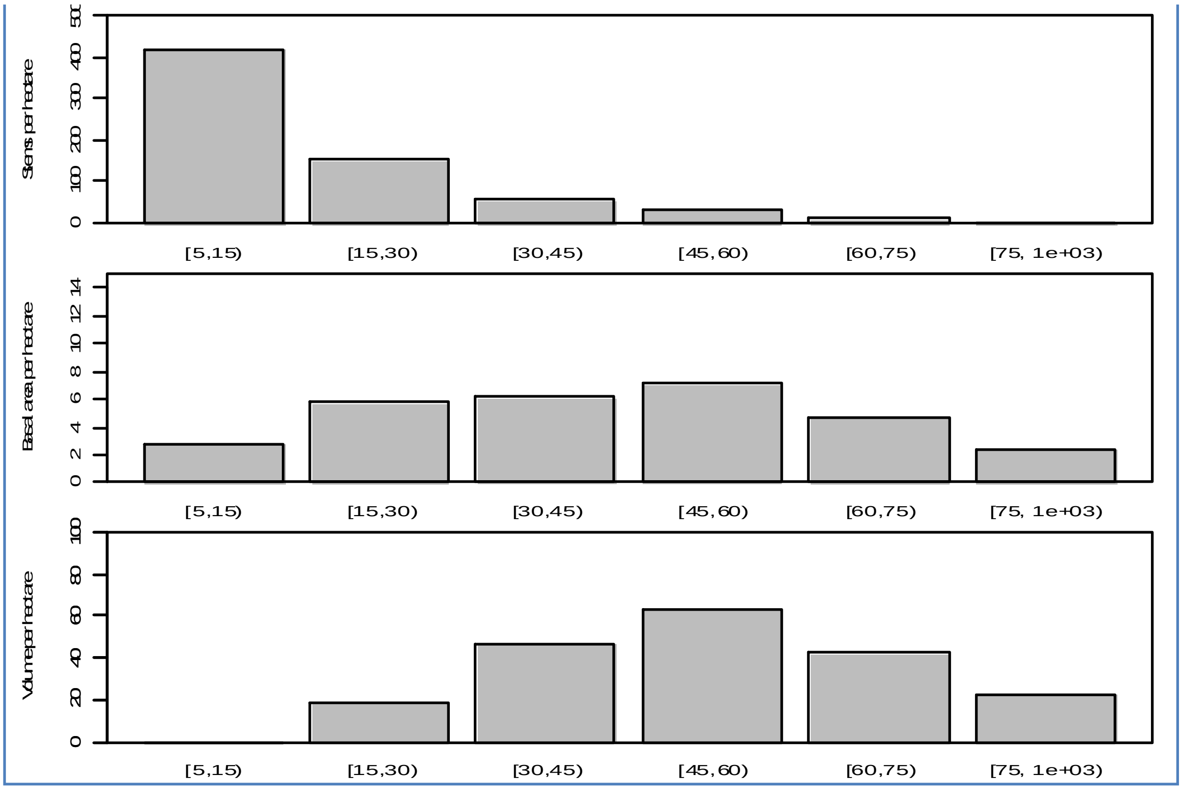


Figure 12 Size structures of all trees in the 100 ha at Compartment 77, Pekan FR

Species composition

The dominant species group in the 30 cm dbh and below are the NDLHW and NDMHW (Figure 13). Both groups occur in all size classes but tend to have lower proportion represented in the larger size class. The DNM is the least dense species group throughout the size classes. The DM representation was also very low, but existed throughout the size classes. The most obvious species groups are the RAMIN and BN. The species are represented in all size classes, but are more dominant in the larger size classes. The graph on basal area and volume illustrates that both species are the dominant species occupying the growing space in the area. Ramin has more larger size trees per unit area as compared to bintangor for the trees greater than 60 cm dbh.

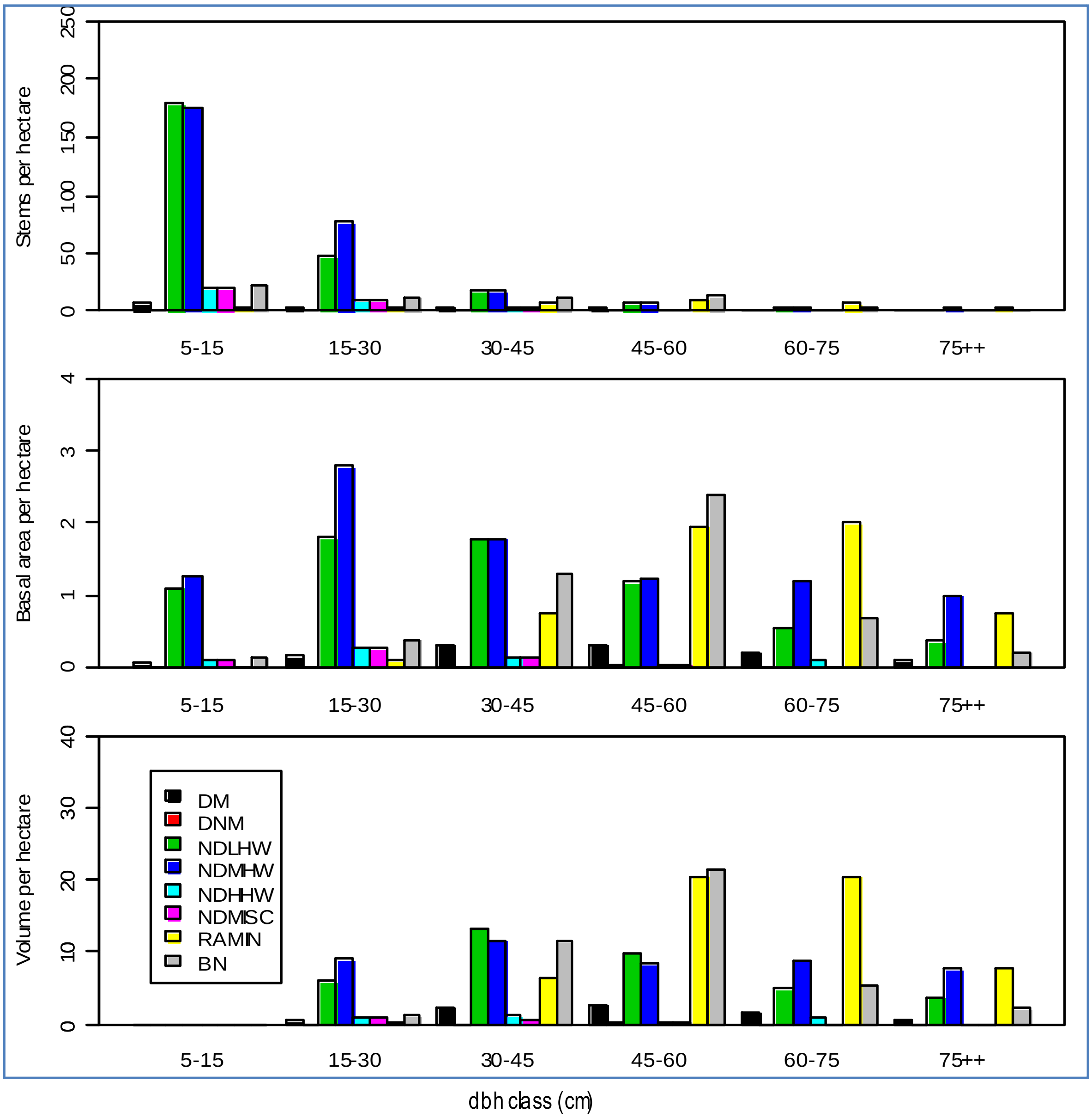


Figure 13 Distribution of species group in the 100 ha at Compartment 77, Pekan FR

Optimum cutting cycle and initial growing stock

Using the GYMTPSF, the projected volume using all residual stands are shown in Table 18 and Figure 14. The projections were done for a period of 120 years. Projection for total trees and volume for *G. bancanus* is shown in Figures 15 and 16.

Table 18 Volume projection after felling by blocks

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

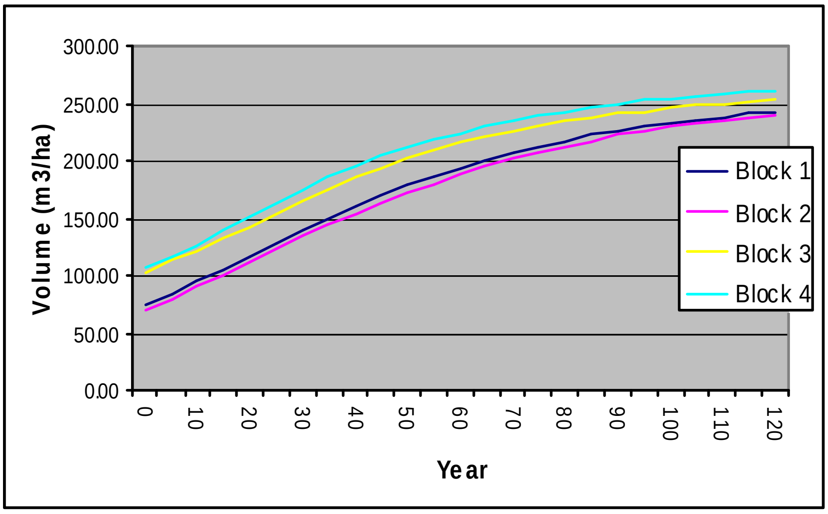


Figure 14 Volume (m^3) projections after felling

Figure 15 Projected number of *G. bancanus* stands (trees ha^{-1}) for 120 years

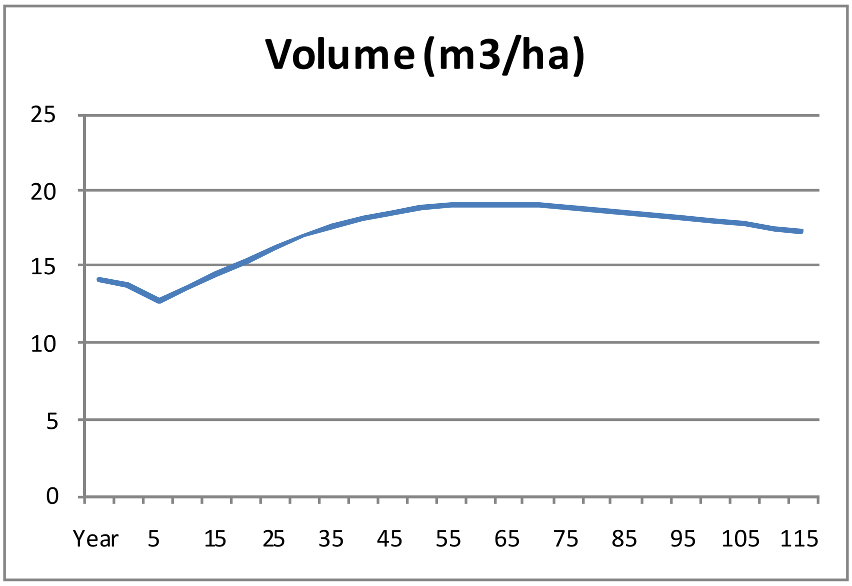


Figure 16 Projected volume (m^3ha^{-1}) of *G. bancanus* trees for 120 years

The results also indicated 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 indicated in Table 19. The initial growing stock after felling that has to be retained in the forest is at 100 m^3ha^{-1} (dbh $\geq$ 15 cm) for all species. If the stand is to be managed at a cutting cycle of 40 year, the maximum gross harvestable volume for the whole stand is projected to be at 72 m^3ha^{-1} of which 8.9 m^3ha^{-1} is of *G. bancanus* .

Table 19 Mean volume increment and the optimum cutting cycle 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

4.0 CONCLUSIONS

Pekan FR is considered as the main area of *G. bancanus* in Peninsular Malaysia. However, *G. bancanus* is not distributed or abundantly available in the whole parts of Pekan FR. There are areas of rich, moderate and poor of *G. bancanus* in terms of stocking. Factors contributing to the natural distribution of *G. bancanus* in Pekan FR are essential and need to be identified as the information could lead to a better management of this species.

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* .

5.0 RECOMMENDATIONS

5.1 Sustainability of *Gonystylus bancanus* Resource

Based on forest inventory figures from elsewhere in Peninsular Malaysia and Sarawak, Lim *et al.* (2004) recognize that Pekan FR has the most resource-rich known stand of *G. bancanus* in Malaysia and possibly in the whole area of its distribution range. Moreover, of the forest reserves in the east and west coasts of Peninsular Malaysia, Pekan FR was identified as having the highest stocking of *G. bancanus* (Blackett & Wollesen 2005; Feilberg & Sorensen 1999).

Therefore, nationally and internationally, Pekan FR is the most important natural habitat of *G. bancanus* (UNDP/GEF 2007). Thus, it is important to maintain the sustainability of the *G. bancanus* resource in the Pekan FR through wise utilization and conservation measures of the species

5.2 Management

According to ITTO (2007), generally there appears lack of information on basic biological characteristics, ecology and regeneration patterns of *Gonystylus* species, particularly *G. bancanus*, in their natural habitats. The basic information including ecological characteristics of *G. bancanus* could greatly enhance to knowledge of the silvicultural treatments as well as sound harvesting methods that could reduce impact on the PSF. These studies have provided some basic ecological information on *G. bancanus* as required by ITTO (2007).

In addition, UNDP/GEF (2007, 2008) had proposed areas for production and conservation in Pekan FR. Areas without significant stands of commercial species, especially *G. bancanus*, were expected to have low economic value and thus to be retained as conservation zone. In addition, harvesting operation in this conservation zone is unlikely profitable due to its low timber productivity, and furthermore harvesting in PSF is fairly expensive (Salleh *et al.* 2008).

5.3 Timber Harvesting

In terms of cutting limit, a combination of high and low cutting limits based on species and species group is suggested. Based on this study, it is proposed that minimum cutting limit for main commercial species such as *G. bancanus* and dipterocarps should be as high as about 60 cm dbh, while for *Calophyllum* species should be at medium size of 50 cm dbh and other species a little bit lower at 45 cm dbh. This is to control over-exploitation of highly commercial species and to include relatively small diameter-sized species, which currently have higher cutting limits. It is also to maintain the original species composition.

For sustainable utilization of timber in Pekan FR, its annual coupe should be calculated based on findings of this study. As a note, the current cutting cycle for SEPPSF areas, including Pekan FR, is set at 55 years.

5.4 Conservation

Beside the conservation areas proposed by the UNDP/GEF (2007), additional conservation areas inside the production zone shall be established in order to have some intact forest areas in highly commercial subtypes. Based on this study, it shows that plot at Compartment 100 of Pekan FR is having more *G. bancanus* stands as compared to other plots in Compartments 156 and 200. The establishment of a 400-ha virgin jungle reserve (VJR) at Compartments 100 and 101 by the Forestry Department of Pahang (Khali Aziz *et al.* 2009) was justified as the area is considered as economically richest area in Pekan FR (Blackett & Wollesen 2005).

5.5 International Issue on *Gonystylus* Species

CITES subjects the international trade of endangered species to varying degrees of control by listing selected species in three appendices according to the degree of threat and protection required (ITTO 2007). Appendix I applies the most stringent controls on species threatened with extinction. Appendix II regulates trade in species that could potentially lead to extinction and Appendix III includes species listed by an individual country in an effort to enlist international cooperation to control trade from that country.

Though the regulation is applied to all *Gonystylus* species, the main species involved in the trade is *G. bancanus* (Shamsudin 1996; Soerianegara & Lemmens 1994). The listing of *G. bancanus* in Appendix II was not intended to curtail the trade but to make sure of export and re-export permits to regulate the trade and enable the tracing of the original source of the wood (ITTO 2007). Positively, the listing of *Gonystylus* species in Appendix II of CITES is one way of helping to ensure the sustainability of *G. bancanus* resource. It is because Appendix II also requires that traded *Gonystylus* species timbers meet the requirements of sustainable production. Therefore, sufficient information on *G. bancanus* is important in preparing the non-detriment findings (NDFs) that should be conducted by the scientific authority to set the annual quota for the trade (ITTO 2007; MTIB 2004; Shamsudin *et al.* 2005).

Nonetheless, based on this study and other studies such as Blackett and Wollesen (2005) and UNDP/GEF (2006), it was found that, generally *G. bancanus* is abundant in the Pekan FR. If the listing of *Gonystylus* species in Appendix II in one way or another give some kind of problems and limitations to Malaysia as the exporter country, the listing should be downgraded to Appendix III, which is relatively less stringent. It is because listing of *Gonystylus* species in Appendix III is considered acceptable in ensuring the *G. bancanus* sustainability.

6.0 IMPLICATIONS FOR PRACTICE

6.1 Management and Harvesting

i. Existing forest areas with deep peat depth, particularly of more than 5 m, should be properly safeguarded, maintained and used specifically for forestry purposes. These are areas where *G. bancanus* dominates and is abundantly available.

ii. The current RIL method has showed minimal impacts on the residual stands and therefore should be continued and encouraged of their usage. Nonetheless, a cheaper alternative RIL method such as long haulage cable system (LHCS) could be used as well in order to lower the harvesting costs, as long as the method is proven efficient.

iii. Based on minimal impacts, to ensure a fairly high timber production and to maintain species ratio before and after harvesting, the minimum cutting limits for sustainable timber production in Pekan FR are suggested as follows:
   - 60 cm dbh for *G. bancanus* and dipterocarps
   - 50 cm dbh for *Calophyllum* species
   - 45 cm dbh for other species

6.2 Conservation

i. The established ecological plots at Compartments 100, 156 and 200 should be maintained for long-term ecological data monitoring and collection.

ii. The authorities should prepare and execute regular relevant activities in the established virgin jungle reserve (VJR) sites at Pekan FR such as site monitoring, maintenance, ecological data collection and conducting phenological observations. Other additional conservation features such as a seed production area (SPA) and gene bank also need to be established.

iii. The existing disturbed and poorly-stocked logged-over areas could also be restored with some commercial species including *G. bancanus* via forest rehabilitation programmes.

6.3 Future Research

i. The current research and monitoring work conducted in this study should be continued and expanded.

ii. Growth and yield plots should be established and monitored in the harvested PSF in order to gather more data on the PSF ecosystem. The entire study plots in Compartment 77, Pekan FR, should be allocated as a long-term research area for the growth and yield study and also other studies such as wind-throw effects, hydrological characteristics and stand dynamics and structures.

iii. Study on determining alternative RIL method beside the RTH in order to minimize total costs of harvesting. It is because the machine might be too expensive for small harvesting contractors.

7.0 ANNEXES

Annex 1 The peat swamp forest in Pekan FR, Pahang

Annex 2 The *G. bancanus* tree

Annex 3 Condition of ecological plot in Compartment 100, Pekan FR

Annex 4 Condition of ecological plot in Compartment 156, Pekan FR

Annex 5 Condition of ecological plot in Compartment 200, Pekan FR

Annex 6 The *G. bancanus* seedlings

Annex 7 The *G. bancanus* logs

Annex 8 The study site in Compartment 77, Pekan FR

Annex 9 Potted *G. bancanus* seedlings ready for field planting

8.0 BIBLIOGRAPHY

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