DYNAMICS OF DIPTEROCARP SEEDLINGS IN FOREST FRAGMENTS IN SABAH, MALAYSIA

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ABSTRACT

Primary rainforest once dominated the landscape of the Malaysian state of Sabah. Since the 1950s, extensive areas of these forests have been exploited in the pursuit of socio-economic gains. Some have been degraded through logging while others converted to non-forestry uses. For the latter, only remnants of forest patches existed in the agricultural landscape. Forest fragments are known to support high levels of biodiversity and potentially could promote landscape connectivity within the agricultural landscape. The aim of this study was to investigate the dynamics of dipterocarp seedlings in forest fragments in relation to their size and quality. A total of 12 transects were established in 10 sites; one transect each for eight forest fragment ranging from 3 to 3,290 ha, two in continuous logged forests (LF: 33,969 ha), and two in undisturbed primary forests (PF: 44,800 ha). At each transects, one to three 50x50 m main plot(s) were established at 500 m intervals along a line transect. Natural dipterocarp seedlings were measured in twenty $1m^2$ quadrats established in a stratified random manner within each main plot. Vegetation structure (tree density, tree species, canopy cover, ground cover, and litter layers) and environmental conditions (light, soil moisture and pH, soil nitrogen, phosphorus and carbon, and C:N ratio) were quantified within the main plot. Dipterocarp seedlings of three ecological contrasting species i.e. *Parashorea malaanonan* (PM, light demander), *Dryobalanops lanceolata* (DL, intermediate), *Hopea nervosa* (HN, shade tolerant) were planted randomly in 30x36m in the center of each main plot to examine survival, growth and herbivory rates. The purpose of using planted seedlings was to standardize their age and species composition across study sites. Leaf litter decomposition rates of the same species (PM, DL and HN) were quantified from 5 litterbags in a 10x5m plot within each main plot for 120 days (total of 15 bags per plot and 480 litter bags in all sites). The abundance of natural dipterocarp seedlings in PF ($\bar{x}_{density}$=5.27 seedlings m^{-2}±0.73(SE); $\bar{x}_{richness}$=0.29 species m^{-2}±0.03(SE)) was 6 to 25 times higher than in LF ($\bar{x}_{density}$=0.38 seedlings m^{-2}±0.05; $\bar{x}_{richness}$= 0.16 species m^{-2}±0.03) and FF ($\bar{x}_{density}$=0.04 seedlings m^{-2}±0.02; $\bar{x}_{richness}$=0.03 species m^{-2}±0.01), and increased with increasing forest fragment size. Forest quality characterized by abundance of dipterocarp trees, canopy structure, soil moisture content and low soil pH was highest in PF and increased with increasing forest fragment size. In relation to forest quality, dipterocarp seedlings abundance increased with increasing forest quality. Survival rates of the planted seedlings in FF (range: 30% to 70%) were *ca.* 10% lower than PF (range: 60% to 80%) and LF (range: 50% to 80%) and increased with increasing forest fragment size and forest quality. Seedlings growth and herbivory, however, was highest in FF due to higher light environment and decreased with increasing forest fragment size and quality. Leaf litter decomposition rates of three dipterocarp species were highest in PF (range: 47-58%); followed by LF (range: 32-47%) and FF (range: 28-40%), and increased with increasing forest fragment size and quality. The result from this study suggested that forest fragments larger than 12 ha had responded to artificial regeneration, thus suggested such forest fragments be retained and should not be replaced for other uses.

Keywords: dipterocarp seedlings, forest fragments, forest quality, leaf litter decomposition

ABSTRAK

Dinamik Anak Pokok Dipterocarp di Hutan Tersepih Sabah, Malaysia

Pada asalnya, landskap di Sabah, Malaysia dilitupi oleh hutan dara yang luas. Hutan ini mula diterokai sejak 1950an bagi tujuan perkembangan sosial-ekonomi. Sejak itu, hutan tersebut mengalami kadar degradasi yang teruk. Kemudiannya, hutan dara ini ditukar kepada kawasan perladangan dan terhasil hutan terserpih di sekitar ladang. Hutan terserpih diketahui mengandungi kepelbagaian hutan yang tinggi dan penting untuk dilindungi. Tujuan kajian ini adalah untuk menyiasat dinamik anak pokok dipterocarp di hutan tersepih berhubung dengan saiz dan kualiti. Dua belas kawasan telah dikaji; lapan kawasan adalah hutan tersepih bersaiz 3 hingga 3,290 ha serta dua kawasan hutan berterusan iaitu telah dibalak (LF, 33,969 ha) dan hutan dara (PF, 44,800 ha). Satu hingga tiga 50x50m plot utama dibina pada selang 500m mengikut transek di setiap kawasan kajian. Anak pokok dipterokap asli dicerap dalam dua puluh kuadrat $1m^2$ *di setiap plot utama. Struktur hutan (kepadatan dan spesies pokok, silara hutan, vegetasi penutup bumi, dan lapisan sarap hutan) dan keadaan persekitaran (cahaya dan, kelembapan, pH, nitrogen, fosforus, karbon, dan nisbah C:N tanah) diukur di setiap plot utama. Tiga spesies anak pokok dipterocarp iaitu Parashorea malaanonan (PM, peminat cahaya), Dryobalanops lanceolata (DL, perantara), Hopea nervosa (HN, peminat teduh) ditanam secara rawak di 30x36m plot bagi mengkaji kadar kematian, pertumbuhan dan herbivori di setiap plot utama. Penanaman dilakukan adalah supaya umur dan komposisi spesies anak pokok diseragamkan bagi setiap kawasan kajian. Kadar penguraian daun-daun sarap tiga spesies dipterokarp (PM, DL dan HN) ditentukan melalui 5 beg sarap di 10x5m plot selama 120 hari (sejumlah 15 beg di setiap plot utama). Anak pokok dipterokarp asli di PF (*$\bar{x}_{kepadatan}$*=5.27 pokok* m^{-2}*±0.73(SE);* $\bar{x}_{kekayaan}$ *=0.29 spesies* m^{-2}*±0.03 (SE)) adalah 6 hingga 25 kali lebih tinggi daripada LF (*$\bar{x}_{kepadatan}$ *=0.38 pokok* m^{-2}*±0.05;* $\bar{x}_{kekayaan}$ *=0.16 spesies* m^{-2} *± 0.03) dan FF (*$\bar{x}_{kepadatan}$ *=0.04 pokok* m^{-2} *± 0.02;* $\bar{x}_{kekayaan}$ *=0.03 spesies* m^{-2} *± 0.01), dan meningkat dengan peningkatan saiz hutan tersepih. Kualiti hutan (diwakili oleh kepadatan pokok dipterokarp, silara hutan dan kelembapan tanah yang tinggi serta pH tanah yang rendah) adalah tertinggi di PF dan meningkat dengan peningkatan saiz hutan tersepih. Berhubung dengan kualiti hutan, anak pokok dipterokap asli meningkat dengan peningkatan kualiti hutan. Kadar kehidupan anak pokok dipterokarp yang ditanam di FF (julat: 30-70%) adalah 10% lebih rendah berbanding PF (julat: 60-80%) dan LF (julat: 50-80%) dan meningkat dengan peningkatan saiz dan kualiti hutan tompok. Kadar pertumbuhan dan herbivori anak pokok adalah lebih tinggi di FF disebabkan oleh persekitaran cahaya yang tinggi dan menurun apabila saiz dan kualiti hutan tompok meningkat. Kadar penguraian daun sarap bagi semua spesies adalah tertinggi di PF (julat: 47-58%), diikuti oleh LF (julat: 32-47%) dan FF (julat: 28-40%) dan meningkat dengan peningkatan saiz dan kualiti hutan tompok. Hasil kajian ini menunjukkan hutan tersepih yang bersaiz lebih daripada 12 ha mempunyai keupayaan untuk regenerasi secara penanaman semula. Sehubungan dengan itu hutan terserpih tersebut hendaklah dikekalkan dan tidak patut ditukar kepada kegunaan lain.*

Kata kunci: anak pokok dipterokarp, hutan tersepih, kualiti hutan, penguraian sarap daun

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LIST OF ABBREVIATION

AIC	-	Akaike Information Criteria
AMSL	-	Above mean sea level
BDFFP	-	Biological Dynamics of Forest Fragments project
C	-	Carbon
CAIMS	-	Conservation Areas Information & Monitoring System
CI	-	Confidence intervals
DOS	-	Department of Statistic Malaysia
DL	-	*Dryobalanops lanceolata*
HCV	-	High Conservation Value
IBT	-	Island Biogeography Theory
LAD	-	Leaf area damage
LL	-	Leaf loss
LF	-	Logged Continuous Forest
ENSO	-	El-Nino Southern Oscillation
FAO	-	Food and Agriculture Organization
FF	-	Forest fragments
GLMM	-	Generalized Linear Mixed Models
GDP	-	Growth Domestic Product
HN	-	*Hopea nervosa*
MFR	-	Malua Forest Reserve
MPOB	-	Malaysia Palm Oil Board
N	-	Nitrogen
P	-	Phosphorus
PAR	-	Photosynthetic active radiation
PCA	-	Principle Component Analysis
PFD	-	Photon flux density
PFR	-	Permanent Forest Reserve
PF	-	Continuous Primary Forest
PM	-	*Parashorea malaanonan*
PRIN	-	Principal component scores
RGR	-	Relative growth rates
RIL	-	Reduced Impact Logging
RSPO	-	Roundtable on Sustainable Oil Palm
SAR	-	Species-area relationship
SLA	-	Specific leaf area
SEA	-	Southeast Asia
SFD	-	Sabah Forestry Department
VJR	-	Virgin Jungle Reserve

LIST OF SYMBOLS

%	-	Percentage
ca.	-	Around or about
$<$	-	Less than
$>$	-	Greater than
$\leq$	-	Smaller than or equal to
$\geq$	-	Greater than or equal to
$^{\circ}$	-	Degree
$'$	-	Minute
$''$	-	Second
-	-	Minus
=	-	Equal to
$\bar{x}$	-	Mean
$\pm$	-	plus-minus
Δi	-	Delta AIC
μ	-	Micro
C	-	Celsius
X	-	By or times
cm	-	Centimetre
d^{-1}	-	Evapotranspiration
e	-	Exponential
e.g.	-	For example
H_2O	-	In water solution
ha	-	Hectare
ha^{-1}	-	Per hectare
$hour^{-1}$	-	Per hour
i.e.	-	That is to say or in other words
k	-	mean annual decomposition rates
Km	-	Kilometre
Kg	-	Kilogram
m	-	Metre
mm	-	Millimetre
m^2	-	Square metre
m^{-2}	-	Per square metre
m^3	-	Cubic metre
ppm	-	Parts per million
s^{-1}	-	Per second
SE	-	Standard error
$year^{-1}$	-	Per year

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CHAPTER 1

INTRODUCTION

1.1 Background

The forests of Southeast Asia (SEA) are dominated by trees in the Dipterocarpaceae family, which comprise, in the Asian tropics, at least 500 species distributed across Borneo, Sumatra, Java, the Malay Peninsula and the wetter parts of Philippines (Primack and Corlett, 2005). Trees in this family can reach a diameter of well over 1 m and grow to height in excess of 70 m, have uniformly excellent timber qualities and play a dominant role in the economics of Asian forests (Whitmore, 1990; Ross, 2004). As a result of decades of industrial logging, much of the region's lowland dipterocarp forests have been heavily degraded (Whitmore, 1997; Ross, 2004). These degraded forests, particularly in Malaysia and Indonesia, are often converted to agricultural plantations.

Land use policy in Malaysia, and the development of plantations, has largely been driven by the National Agriculture Policy (1984-2010), which was intended to increase agricultural production as a means to support the nation's socio-economic development (Jomo *et al.*, 2004; Murad *et al.*, 2008). Agricultural development in Malaysia, over recent decades, has been dominated by the expansion of oil palm plantations (Abdullah and Nakagoshi, 2007) that now occupies 4.7 million ha or 15% of the total landmass (33 million ha) of Malaysia (DOS, 2013). Economically, it contributes about RM50 billion or 5% of Malaysia's Gross Domestic Product (MPOB, 2013; DOS, 2013).

In Sabah, oil palm plantations have expanded from approximately 100,000 ha in 1970 to over 1.4 million ha (or 20% of Sabah's land area) in 2013 (DOS, 2013; MPOB, 2013). Most of this development has been driven by the private sector on state-owned lands, though plantations have, in some cases, encroached into forest reserves (SFD, 2010; Foster *et al.*, 2011; Osman *et al.*, 2012). As plantations are developed, small patches of forest are often left behind (Benedick *et al.*, 2006; Hill *et al.*, 2011). These embedded patches of forest usually remain unplanted due to inaccessibility (steep or rocky terrain), and/or their proximity to water bodies (Fitzherbert *et al.* 2008; Foster *et al.*, 2011). A key ecological concern about these forest fragments is their functional integrity within agricultural landscape (RSPO, 2013; HCVRN, 2014).

Forest fragments are known to support high levels of biodiversity (Benedick *et al.* 2006) and improve species richness (Lucey *et al.* 2014) and potentially could be important in promoting landscape connectivity within the agricultural landscape (Proctor *et al.* 2011). However, the assumption that forest fragments can still support high biodiversity and ecosystem functioning while maintaining viability (including the regeneration of dipterocarps) has not previously been tested. Seedling recruitment has been shown to fail within forest fragments when the overtopping canopy structure was disturbed (Benetez-Malvido, 1998; Bruna, 2002; Cramer *et al.*, 2007), most likely due to changes in microclimate (Ferreira and Laurance *et al.*, 1997; 1998; Laurance *et al.*, 2002), exposure to increased wind speeds and turbulence and edge effects, leading to further habitat disturbance (Laurance *et al.*, 1997; Ferreira and Laurance, 1997). The severity of these environmental changes within forest fragments depends on the intensity of disturbance and fragmentation. For example, selective logging within forests fragments in Brazil resulted in a 15% increase in canopy openness with a corresponding reduction in soil moisture of 50% compared to undisturbed forest fragments (Guarino and Scariot, 2012). Moreover, changes within fragments are correlated with fragment size (Ranta *et al.*, 1998; Laurance *et al.*, 2002). In a study in Brazil, Benitez-Malvido and Martínez-Ramos (2003) found that light intensity in 1 ha forest fragments was ~30% higher than in 100 ha forest fragments.

In addition, the loss of seed-producing trees in forest fragments (particularly dipterocarps which are targeted for their timber) would likely result in lower seedling abundance than continuous areas of forest (William-Linera, 1990; Bierregaard *et al.*, 1992; Ferreira and Laurance, 1997; Laurance *et al.*, 1998). The frequency of flowering is often disrupted by fragmentation (Fuchs *et al.* 2003; Laurance *et al.*, 2002; Herrerias-Diego *et al.*, 2006), and plant-animal interactions in terms of seed dispersal and pollination can also be impacted (Aizen and

Feinsinger, 1994; Cunningham, 2000; Chapman *et al.*, 2003). Seedlings, which do recruit into fragmented forests of show higher mortality rates as a result of increased animal browsing (Dudt and Shure, 1994; Benitez-Malvido *et al.* 1999; Terbogh *et al.*, 2001; Faveri *et al.*, 2008).

Another indicator of ecological functioning in ecosystems is the rate of litter decomposition. Leaf litter stores plant nutrients but unless they decompose, it can act as physical barrier for seedling establishment (Molofsky and Augspurger, 1992; Dupuy and Chazdon, 2008). In fragmented forests, both light and temperature regimes are key factors influencing the rate of litter decomposition (Burghouts et al., 1992; Laurance et al., 2002; Bruhl et al., 2003; Vasconcelos and Laurance, 2005; Vasconcelos et al., 2007; Barlow et al., 2007). These findings are supported by regional studies, which have indicated that mean annual decomposition rates (k) in tropical forests (2.33±2.44 k year^{-1}) are higher than in temperate forests (0.36±0.17 k year^{-1}) because of warmer tropical climates (Aerts, 1997; Berg *et al.*, 1993). In addition to climatic factors, the rate of litter decomposition is also dependent on the extent of soil biota activity and the abundance and distribution of invertebrate decomposers (Didham, 1998; Riutta *et al.*, 2013).

Studies on the impacts of forest fragmentation in Sabah, Malaysia have focused on ants (e.g. Bruhl *et al.*, 2003; Bickel *et al.*, 2006; Tawatao *et al.*, 2011), butterflies (Benedick *et al.*, 2006; Hill *et al.*, 2011; Lucey and Hill, 2012) and primates (Goossens *et al.*, 2005; Boonratana, 2013). The research on the effect of forest fragmentation on natural regeneration of diperterocarp remains scarce. Hence, understanding the impacts of forest fragmentation on dipterocarp seedlings dynamics is crucial, which can be contributed in the forest restoration and management solutions within plantation-dominated landscapes.

1.2 Justification

It has been well established that unplanned land use for forestry or agricultural uses affect the local microclimates of forest fragments (Laurance *et al.*, 1997; Laurance *et al.*, 2002). As a consequence of such ad hoc land modification, the occurence of dipterocarp seedlings in forests would be uneven (Bruna, 2002;

Guarino and Scariot, 2012). In addition, the effect of intrusion factors such as herbivory would further disrupt seedling regeneration within forest fragments (Rao *et al.* 2001; Terborgh *et al.* 2001). These intrusions and perturbations would also affect the rates of litter decompositions that would affect seedling recruitment (Riutta *et al.*, 2013). Results from this study would contribute to the understanding of the ecosystem functioning within forest fragments.

In order to understand the dynamics of dipterocarp seedlings in forest fragments, six hypotheses were formulated in this research as follows:

a. the occurrence, density and species richness of naturally regenerating dipterocarp seedlings decline as fragment size decreases;
b. forest quality declines as fragment size decreases;
c. the occurrence, density and species richness of naturally regenerating dipterocarp seedlings increase with increasing forest quality;
d. survival and growth rates of planted dipterocarp seedlings increase with increasing fragment sizes and forest quality;
e. herbivory rates of planted dipterocarp seedlings increase as forest fragment size and quality decrease and;
f. leaf litter decomposition rates decrease as forest fragment size and quality decrease.

1.3 Objectives

The main objective of this study was to examine the dynamics of dipterocarp seedlings in relation to forest fragment size and quality. The specific objectives of the research were to:

a. Determine the status of naturally regenerating dipterocarp seedlings with respect to their occurrence, density and species richness in forest fragments of different sizes, and in continuous forests;

b. Identify biotic and abiotic variables that best explain forest quality within the targeted forest fragments and continuous forests using principal component analysis (PCA)

c. Test the relationship of forest quality with natural dipterocarp seedlings occurrence, density and species richness;

d. Assess ecosystem function within forest fragments of varying sizes and continuous forests by:

   i) measuring survival and growth of planted dipterocarp seedlings (*Parashorea malaanonan*, *Dryobalanops lanceolata* and *Hopea nervosa*) which were selected on the basis of their varying ecological traits,

   ii) quantifying herbivory rates of planted dipterocarp seedlings,

   iii) examining leaf litter decomposition rates.

CHAPTER 2

LITERATURE REVIEW

2.1 Tropical forests of Sabah

2.1.1 Distribution and extent

The tropical forests of Sabah comprise lowland and hill dipterocarp forest, swamp, beach, heath, limestone and montane forests (Fox, 1972 cited in CAIMS, 2005a; Fox, 1978). These forests extend from the coastal areas to as high as 3,000 m above mean sea level (AMSL). In the 1980s, there were *ca.* 4.5 million ha of forests in Sabah representing 60% of the 7.4 million ha of the total landmass (Marsh and Greer, 1992). Among the forests types, dipterocarp forests are the most extensive vegetation type in Sabah (Fox, 1972 cited in CAIMS, 2005a; Newbery *et al.*, 1996).

Lowland and hill dipterocarp forests are found from 0 up to 900m AMSL and can be categorized into five main types according to the dominant timber species i.e. Type 1, *Parashorea malaanonan*; Type 2, *Parashorea tomentella* and *Eusideroxylon zwageri*; Type 3, *Shorea* spp., and *Eusideroxylon zwageri*, Type 4, *Shorea* spp. and *Dipterocarpus* spp. and Type 5, *Parashorea malaanoanan* and *Dryobalanops lanceolata* forests (Fox, 1972 cited in CAIMS, 2005a). These forests are mostly located in the east coast of Sabah stretching westwards from Silabukan to the lower parts of the Segama and Kinabatangan (Figure 2.1). Type 1 forests are primarily located in the Darvel Bay area, which stretch from east Silabukan to Semporna peninsular. Type 2 forests can be found in Sandakan region and from lower parts of Segama and Kinabantangan to the west in Lokan area. The dominant species of Type 2 forests are *Parashorea tomentella* and *Eusideroxylon zwageri* as well as other associated species including *Parashorea malaanonan*, *Shorea johorensis* and *Dryobalanops lanceolata*.

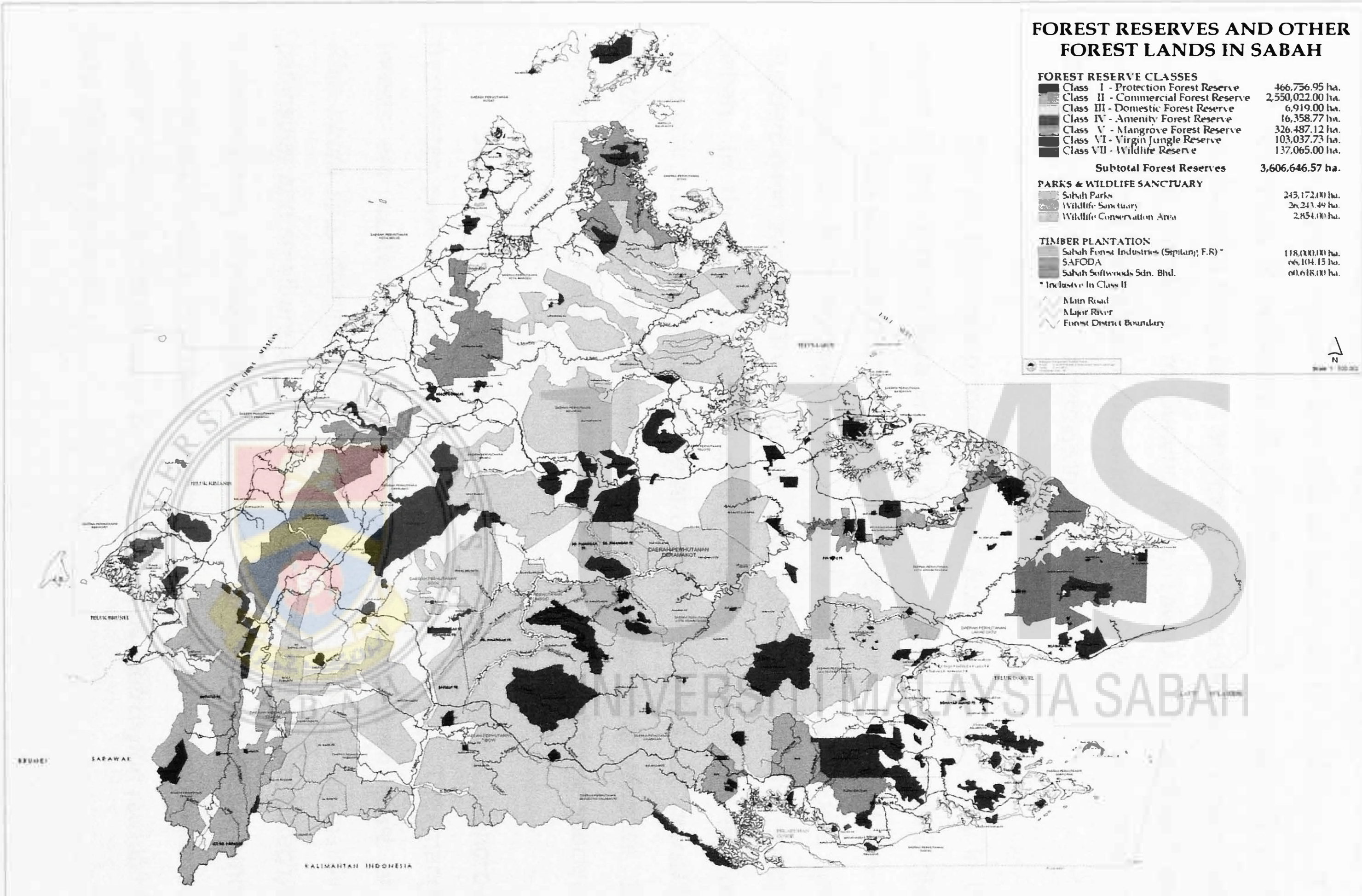

Figure 2.1: Map of forest reserves and other forested land in Sabah.
Source : Sabah Forestry Department (2012)