

TREES AND REGENERATION IN RUBBER AGROFORESTS AND OTHER FOREST-DERIVED VEGETATION IN JAMBI (SUMATRA, INDONESIA)

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ABSTRACT

The rubber agroforests (RAF) of Indonesia provide a dynamic interface between natural processes of forest regeneration and human's management targeting the harvesting of latex with minimum investment of time and financial resources. The composition and species richness of higher plants across an intensification gradient from forest to monocultures of tree crops have been investigated in six land use types (viz. secondary forest, RAF, rubber monoculture, oil palm plantation, cassava field and *Imperata* grassland) in Bungo, Jambi Province, Indonesia. We emphasize comparison of four different strata (understory, seedling, sapling and tree) of vegetation between forest and RAF, with specific interest in plant dependence on ectomycorrhiza fungi. Species richness and species accumulation curves for seedling and sapling stages were similar between forest and RAF, but in the tree stratum (trees > 10 cm dbh) selective thinning by farmers was evident in a reduction of species diversity and an increase in the proportion of trees with edible parts. Very few trees dependent on ectomycorrhiza fungi were encountered in the RAF. However, the relative distribution of early and late successional species as evident from the wood density distribution showed no difference between RAF and forest.

Keywords: Diversity indices, species richness, structure, tropical secondary forest

I. INTRODUCTION

Sumatra is the world's fifth largest island and part of the biogeographical 'Sundaland' domain that is widely recognized for its high biodiversity. It harbours a wide variety of natural and derived vegetation types (Laumonier, 1997), from forestland shrub land, wet lands, agriculture and grassland. Although Sumatra is not as rich in Dipterocarpaceae as the island of Borneo, this tree family is still considered to be characteristic of the lowland forests and contributes 3.1% of total tree species diversity in Sumatra as against 6.3% in Borneo (Roos *et al.*,

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2004). Most big trees in late successional stages of the lowland forests, such as Dipterocarpaceae and Fagaceae, have a close association with ectomycorrhiza (EM) fungi (Smits, 1994). In contrast, associations with endomycorrhizal (also indicated as arbuscular mycorrhiza) fungi mainly dominate in early successional trees and agricultural plants (Wang and Qiu, 2006). Early successional stages tend to have low wood density, while late successional trees usually have high wood densities (Swaine and Whitmore, 1988). So, distribution of the wood density of the trees in a mixed-vegetation can be used as an indicator of successional status.

During the nineteen-nineties forest cover in Sumatra declined dramatically. The rate of deforestation or forest conversion in Sumatra was estimated to be about 61% within 12 years (FWI/GFW, 2001). In Bungo district in Jambi province alone, the conversion rate of forest areas was about 25% within 10 years, from 1993 to 2002 (Ekadinata and Vincent, 2005). Loss of forest biodiversity depends largely on the type of land cover to which the natural forest was converted (Gillison and Liswanti, 2004; Tomich *et al.*, 2002). Some forest-derived land cover types still maintain substantial sub-sets of the original forest vegetation and approach the structure of secondary forests (Murdiyarso *et al.*, 2002). From some derived land cover types the forest vegetation can still recover. From other, the loss of biodiversity is likely to be permanent on a relevant time scale of decades. As the late succession dipterocarp trees depend on EM, their recovery potential likely depends on the belowground as well as aboveground impacts of forest conversion on species persistence. Rubber agroforests (RAF) is the main forest-derived land cover type of interest in this regard.

The introduction of *Hevea brasiliensis* ('para rubber') in Sumatra in the first decade of the 20th century caused a revolutionary change in the land use pattern, when the new cash crop was found to be compatible with local forest conditions. The upland rice - crop fallow systems that had been the mainstay of the local economy were replaced with RAFs, of various management intensities (Gouyon *et al.*, 1993; van Noordwijk *et al.*, 1998). Complex RAF is characterized by a substantial share of rubber trees in the total tree biomass, but also by a large diversity in species of native forest trees and understory plants (Laumonier, 1997; Beukema *et al.*, 2007). These RAF systems may well represent the best example of 'domesticated forests' (Michon, 2005) that maintain basic forest ecological processes of regeneration in a highly productive context, and that allows weekly income to be derived by tapping off rubber (Tomich *et al.*, 2002).

Earlier studies have clarified vegetation structure and species composition of RAF (Gouyon *et al.*, 1993; Gillison and Liswanti, 2004; Michon, 2005) and analysed the pteridophyte flora (Beukema and van Noordwijk, 2004) of RAF in Jambi. Local ecological knowledge and farmer management styles for regeneration in cyclical or semi-permanent RAF were analysed by Joshi *et al.*

(2003; 2005). However, none of the existing data sets has compared species richness in the different stages of tree regeneration (seedlings, saplings and trees) in relation to farmer management decisions.

Our analysis of tree and understory data collected in the Jambi project on the options for sustainable management of belowground biodiversity quantified the effect of land use on the composition and species richness of higher plants, with particular attention to plants with known dependency on EM, successional status of the tree species and applicability of the 'shadow species' concept (Rennols and Laumonier, 2006). Comparison of the seedling, sapling and tree strata focused on evidence of successful regeneration of forest diversity in agriculturally managed landscape units.

II. MATERIALS AND METHODS

A. Study area

The study was conducted in Bungo district of Jambi province, which lies between 101°27' and 102°30'E, and between 1°08' and 1°55' S. The Bungo River after which the district is named starts in the piedmont (foothills, 150 – 500 m a.s.l.) where the mountain range of the Bukit Barisan rises above the lowlands (Figure 1). The Bungo river joins the Batang Hari in the flat or mildly undulating lowland peneplain that forms most of Jambi province, with elevations ranging from 50 to 150 m (a.s.l.). Soils of the lowland peneplain are very acid, have low fertility status, leached soils (Ultisols) deposited under marine conditions in the past, with higher clay contents close to the river (van Noordwijk *et al.*, 1998). The piedmont hills were built mainly by granite and andesitic lava. The soils range from shallow to very deep, very acid, moderate to fine texture, well to moderately-excessive drained and generally higher fertility. Soil types are Entisols, and Inceptisol (van Noordwijk *et al.*, 1998).

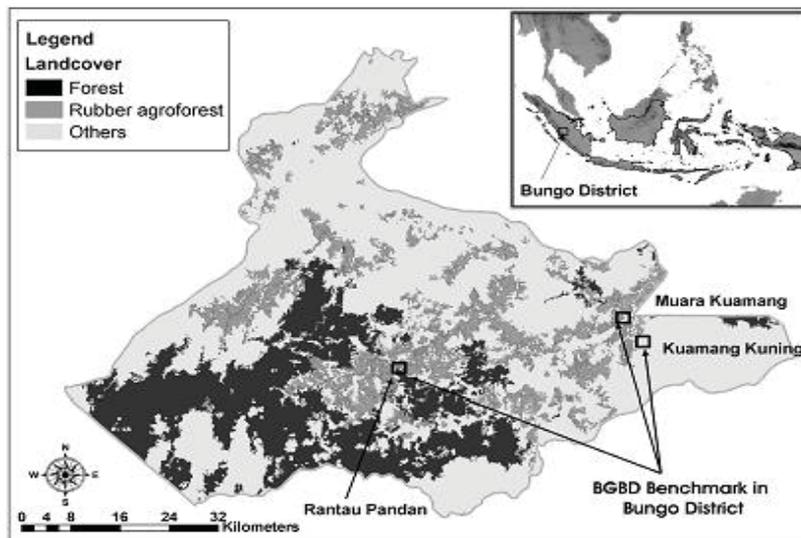


Figure 1. Map of the study area in Bungo District, Jambi Province, Indonesia.

Bungo district has vegetation ranging from forest, agroforest, swamp forest along the river, tree crop plantations and agriculture (upland rice, maize, cassava and paddy rice). Some surveys were initiated in April 2005 for the Sustainable Management of Belowground Biodiversity (CSM-BGBG) project (Giller *et al.*, 2005), with a ‘sampling window’ in the foothills in Rantau Pandan and two in the lowland penneplain in Muara Kuamang and Kuamang Kuning. Selection criteria for these approximately 25 km² windows were the opportunity to capture diversity through the presence of a range of land use types. Sampling within the windows was done in an equidistant grid of points, with additional points to obtain a minimum number of replicates of all major land use strata. To implement this scheme, land cover in Bungo district was interpreted from satellite images of Landsat ETM taken in 2002. In total, 75 km² of study area in Bungo district has been selected. The benchmark area was divided during the field inventory into six classes describing land use type (LUT) as follow:

1. Secondary forest: community managed forest used for extraction of timber for local use and non-timber forest products, forests recovering from selective logging and mature untapped RAF, usually with low density of rubber trees
2. Rubber agroforest (RAF); complex rubber agroforest that is currently being tapped

3. Rubber monoculture (RM); rubber monoculture with intensive management
4. Oil palm plantation (OP)
5. Cassava field (CS); when floristic inventories were conducted, all cassava had been harvested
6. *Imperata cylindrica* grassland (IG)

Relatively scarce land cover classes (river, road, and village) were excluded from the sample design. The number of sample points per land cover class varied between 5 and 12.

The 'sampling window' in Rantau Pandan and Muara Kuamang contained secondary forest (FO) and RAF, each represented by 8 sample plots in each window. Rubber monoculture (RM), was sampled in 6 plots each in Rantau Pandan and Kuamang Kuning. The other land uses, viz. oil palm (OP), crop cassava (CS) and *Imperata* grass land (IG), were only represented in Kuamang Kuning, with 5, 9, and 12 sample plots, respectively.

B. Plot size

In total seventy circular plots of 200 m² (8 m in radius) were laid out. Each plot was divided into a subplot of 50 m² (4 m in radius) and a subplot of 25 m² (2.8 m in radius), nested within the larger plots. All strata of vegetation were recorded. The diameter at breast height (dbh; 1.3 m) of trees ≥ 10 cm within circular plots of 200 m² was measured. Saplings and woody climbers, with dbh less than 10 cm and height of more than 2 m, were recorded from the 50 m² subplots. Similar data were collected for seedlings (consisting of shrubs and woody plants less than 2 m high) and understory (consisting of lianas, herbs, terrestrial ferns and grasses) were recorded within the 25 m² subplots.

Herbarium specimens were collected from each individual tree, except very well known species, and deposited at the Herbarium of the World Agroforestry Centre (ICRAF-SEA). Herbarium specimens were identified at the Herbarium Bogoriense, Bogor, Indonesia. Among all trees sampled in the 6 land use types in Bungo district (544 herbarium specimens), 88.2 % was identified to species level, 5.0 % was identified with a *cf.* note, 6.4 % was identified at genus level, and the rest (0.4 %) remained unidentified.

C. Climate

Generally the climate in Bungo district belongs to A type (Schmidt and Ferguson, 1951). Rainfall data were collected from the nearest climate stations in the sub-districts of Muara Bungo and Rantau Pandan for the period 1998 to 2002 (Figure 2). The mean annual rainfall and number of rainy days in Muara

Bungo were 2,602 mm per annum and 126 days per annum, while in Rantau Pandan these were 2,888 mm per annum and 130 days per annum, respectively.

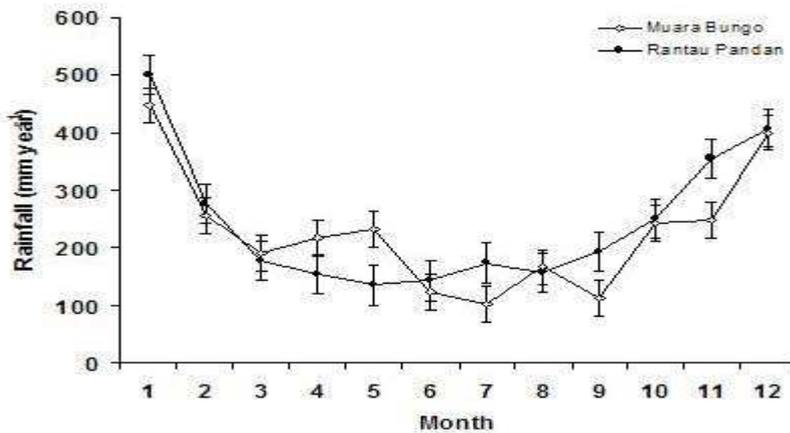


Figure 2. Yearly rainfall for climate stations in Muara Bungo and Rantau Pandan. Bars show standard error of mean (Data: ICRAF).

D. Data analysis: diversity indices and shadow species

Comparison of index diversities (Shanon Wiener and Simpson Index) was made between two land use types, e.g. forest and other land use types, using a *t*-test. Species richness, number of individual flora, number of family, density and basal area were compared between forest and other land use type using analysis of variance (*F*-test), and continued with Dunnet test when it was significant using Statistica 6.0 (StatSoft Inc., USA).

The relationship between species richness and sample size was compared between both land use types in curves of species accumulation, generated from randomly resampling the sample plot data in six reiterations, using R 2.1.1 software developed by Kindt and Coe (2005).

The data were analyzed using ecological standard methods. Abundance of ground cover species was calculated as percentage of a species relative to all species. For each LUT, species richness (the total number of species per land use type) and species diversity, was calculated as the Shanon-Wiener index (Ludwig and Reynolds, 1988):

$$H^3 = - \sum_{i=1}^s p_i \ln p_i$$

where p_i is the proportion of individuals found in the i -th species in each concentric plot or in the whole plot. This index considers the number of species (species richness) and the evenness of their abundance.

Floristic diversity of each LUT was also calculated as the Simpson's diversity index (Ludwig and Reynold, 1988):

$$D_s = 1 - \sum [n_i * (n_i - 1) / N * (N - 1)]$$

where n_i is the number of individuals in the i^{th} species collected, and N is the total number of individual organisms in the plot sample. Comparison of diversity was made between LUT of forest and RAF using a t - test with each plot considered as an independent replicate.

The concept of 'shadow species', as recently introduced by Rennolls and Laumonier (2006) on the basis of a natural forest data set from Jambi was applied separately to the data for seedlings, saplings and trees of the forest and RAF plots. The number of 'shadow species' for species observed once, twice and multiple times was calculated using the relative frequency of observation and a procedure introduced by Rennolls and Laumonier (2006). Shadow species are species whose existence in the land use types can be inferred from the data, but that have not been actually observed. A single observance of the species is called a singleton.

Based on literature, we classified all species of woody plants according to their EM dependency, human use of their edible parts and wood density. Pioneers typically tend to have low wood densities, linked to rapid growth rates and medium-sized trees, while late successional species have high wood densities, grow slowly and reach to greater heights. To classify plants according to their wood density we used a database developed by World Agroforestry Centre (ICRAF-SEA) and available at www.icraf.org/SEA to obtain a midpoint estimate of the wood densities of tree growing in the forest and RAF, and calculated the cumulative frequency of the species according to wood density.

Plants are considered edible if they produce fruits, vegetables, nuts, gums or spices that are used by man. This information is given by Whitmore (1983), Whitmore and Tantra (1986) and Keßler and Sidiyasa (1994), and was cross checked in the context of local ecological knowledge in Bungo district.

To classify species on their EM dependency, we used the information from Smits (1994). Independence in two-way classification of data (e.g. LUT and properties of the trees) was tested using a χ^2 - test, pooling the data for forest and RAF for the three sampling windows.

III. RESULTS AND DISCUSSION

A. Results

1. Floristic characteristics of six land use types in Jambi

The data on floral diversity for the different land use types shows that the main difference, for any layer other than understory vegetation, is between the natural forest plus agroforest (RAF) on one hand, and all other land use types on the other. The number of plant species and families in three strata (e.g. seedlings, saplings and trees) decreased from over 40 per plot in the forest to 9 per plot in the *Imperata* grass land (Table 1).

The stratum of seedlings and saplings shows considerable regeneration in forest and RAF. Species richness of saplings and trees in forest was higher than in RAF, but seedlings' species richness was higher in RAF than in forest. In the further discussion we will focus on a comparison of forest and RAF.

Average plot-level richness and species accumulation curves (Figure 3) for forest and RAF overlapped for seedlings and saplings, but trees and understory differed significantly between the two LUT's when 10 or more plots were considered.

Table 1. Structural characteristics and floristic diversity of land use type of forest, rubber agroforest (RAF), rubber monoculture (RM), oil palm plantation (OP), Cassava field (CS) and Imperata grassland (IG) in Bungo District (Jambi, Indonesia). The area of each land use type is 0.32 ha, 0.32 ha, 0.20 ha, 0.10 ha, 0.18 ha, and 0.24 ha, respectively. Number of plant families given the total number of families found in all plots of a LUT.

Stratum	Parameter	Forest	RAF	RM	OP	CS	IG			
Tree	# Individu	12.4 (1.2)	12.7 (4.5)	ns	12.3 (1.6)	ns	0	1.0 *	0	
	# species	9.6 (1)	6.0 (0.9)	*	1.5 (0.2)	**	0	1.0 *	0	
	# family	8.0 (0.8)	5.3 (0.9)	**	1.4 (0.2)	***	0	1.0 *	0	
	Density (n ha ⁻¹)	621.9 (58.1)	634.4 (56.6)	ns	61.6 (78.4)	ns	0	50.0 *	0	
	Total BA (m ² ha ⁻¹)	5.6 (0.7)	4.9 (0.6)	ns	2.5 (1.4)	**	0	0.2 *	0	
	BA rubber (m ² ha ⁻¹)	0.9 (0.3)	2.6 (1.5)	**	2.3 (0.4)	*	0	0	0	
	Shanon Index	4.5 (6.5E-05)	2.6 (1.8E-03)	**	0.2 (8.6E-12)	***	-	0	-	
	Samson's Index	0.98 (2.8E-05)	0.72 (1.3E-03)	**	0.07 (9.6E-04)	***	-	0	-	
Sapling	# Individu	18.2 (2.8)	18.0 (3.2)	ns	5.3 (1.1)	*	0	0	0	
	# species	11.2 (1.4)	10.6 (1.6)	ns	2.0 (0.8)	**	0	0	0	
	# family	8.8 (0.97)	8.0 (1)	ns	1.8 (0.7)	**	0	0	0	
	Density (n ha ⁻¹)	3650.0 (561.7)	3600.0 (642.4)	ns	1066.7 (229.0)	*	0	0	0	
	Shanon Index	4.3 (7.2E-04)	4.2 (9.6E-04)	*	1.1 (2.1E-03)	***	-	-	-	
	Samson's Index	0.99 (3.8E-06)	0.98 (1.3E-05)	*	0.46 (0.01)	***	-	-	-	
Seedling	# Individu	45.6 (4.2)	60.9 (7.4)	ns	52.2 (4.6)	ns	29.8 (15.6)	ns	12.2 (2.1) ***	4.8 (2.0) ***
	# species	15.4 (1.3)	15.7 (5.5)	ns	8.5 (1.0)	***	2.6 (0.5)	***	2.3 (0.5) ***	1.1 (0.3) ***
	# family	11.3 (1.1)	11.9 (0.9)	***	6.8 (0.9)	***	10.6 (0.9)	***	2.0 (0.4) ***	1.1 (0.3) ***
	Shanon Index	4.3 (8.2E-04)	4.0 (9.0E-04)	**	2.6 (4.4E-03)	***	1.3 (0.02)	***	1.6 (0.02) ***	0.95 (0.004) ***
	Samson's Index	0.98 (3.6E-06)	0.97 (5.3E-06)	**	0.83 (1.5E-04)	***	0.7 (5.6E-04)	***	0.8 (2.3E-04) ***	0.4 (0.006) ***
Under-story	# Individu	38.4 (14.6)	84.1 (30.7)	*	176.3 (37.7)	*	174.2 (34.0)	ns	12.2 (2.1) ns	281.6 (59.9) **
	# species	6.1 (0.7)	7.8 (0.9)	ns	7.6 (1.1)	ns	14.2 (1.2)	***	2.3 (0.5) *	9.2 (1.4) ns
	# family	5.2 (0.5)	7.1 (0.7)	ns	5.8 (0.8)	ns	9.0 (0.7)	*	2.0 (0.4) *	7.1 (1.1) ns
	Shanon Index	2.8 (3.0E-03)	2.1 (2.1E-03)	**	2.7 (5.9E-03)	***	2.8 (0.1)	***	2.1 (0.01) ***	1.7 (0.008) ***
	Samson's Index	0.9 (1.2E-04)	0.7 (2.0E-04)	**	0.89 (1.5E-05)	*	0.9 (1.8E-05)	***	0.8 (1.4E-05) ***	0.7 (5.8E-05) ***

Note : Asterisk denote significant value RAF compare to forest; * at the $p < 0.05$, ** at the $p < 0.01$, *** at the $p < 0.001$, ns denote not significant based on Dunnet test

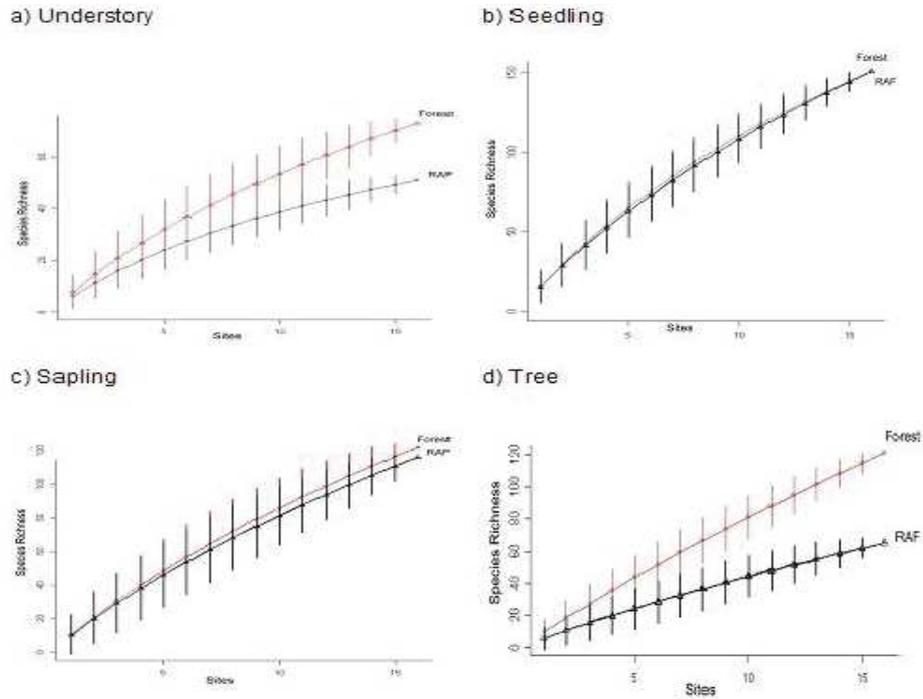


Figure 3. Relationship between number of observed plant species and number of plots included in the analysis for four strata in forest and rubber agroforestry (RAF); vertical lines show standard deviation of results obtained by re-sampling the data

2. Diversity indices

The diversity indices of Shanon Wiener and Simpson showed that diversity of each stratum in forest is consistently higher than in RAF (Table 1).

Diversity of understory in the forest was significantly higher than in RAF (t test = 10.5; probability 0.01). Seedling diversity in the forest was also higher than in RAF (t test = 3.0; probability 0.01), as was the diversity of saplings in the forest and RAF (t test result = 2.5; probability 0.05). Furthermore, diversity of trees in the forest was higher than in RAF (t test = 7.2; probability 0.01).

Rubber monoculture is dominated by rubber, and has a lower diversity of trees, saplings and seedlings than forest or RAF. The floristic diversity of OP, CS and IG were lower than the diversity of RAF and forest. Neither saplings

nor trees were present in OP and IG land use, except for a single tree present in CS at the time of this study.

3. Dominant family and species in the forest and RAF

Arecaceae was the most common family in the understory, and *Euphorbiaceae* was the most common in all other strata in the forest and RAF (Table 2). *Fagaceae*, associated with EM fungi, was one of the five most frequent plant families in the forest. Most of the *Dipterocarpaceae* species encountered were growing in forest plots.

Table 2. The five commonest families present at forest and RAF, in Bungo district, Jambi

Land Uses	No.	Understory	Seedling	Sapling	Tree
Forest	1	Arecaceae (13.2)	Euphorbiaceae (12.3)	Euphorbiaceae (15.6)	Euphorbiaceae (14.8)
	2	Selaginellaceae (5.7)	Rubiaceae (7.5)	Myrtaceae (8.2)	Fagaceae (9.8)
	3	Annonaceae (3.8)	Annonaceae (6.2)	Rubiaceae (6.6)	Myrtaceae (8.2)
	4	Connaraceae (3.8)	Fabaceae (5.5)	Annonaceae (4.9)	Fabaceae (5.7)
	5	Dioscoreaceae (3.8)	Lauraceae (5.5)	Fabaceae (4.1)	Lauraceae (5.7)
RAF	1	Arecaceae (8.2)	Euphorbiaceae (11.1)	Euphorbiaceae (16.4)	Euphorbiaceae (13.6)
	2	Annonaceae (6.9)	Rubiaceae (9.2)	Annonaceae (11.2)	Burseraceae (7.6)
	3	Connaraceae (6.9)	Fabaceae (7.2)	Fabaceae (6.0)	Fabaceae (7.6)
	4	Dilleniaceae (5.5)	Annonaceae (5.9)	Lauraceae (6.0)	Moraceae (7.6)
	5	Vitaceae (4.1)	Lauraceae (5.2)	Rubiaceae (6.0)	Lauraceae (6.1)

Note : value in the brackets is the relative species richness of a family.

The five commonest species were ranked by their importance value index (IVI) in forest and RAF. None of the five commonest species were Dipterocarps (Table 3). In the understory, *Selaginella ornata* is a shared species among the top 5 of both forest and RAF. Although *Euphorbiaceae* are prominent within both land use types, the rubber tree that is dominant in RAF was found in low density in the forests – suggesting either that it spreads as ‘invasive exotic’ into forests or that part of the ‘forest’ represents failed attempts in the past to establish RAF. Other tree species dominant in RAF were *Artocarpus integer* (group of fruit trees), *Parkia sumatrana* (group of fodder trees) and *Parkia speciosa* (group of nuts).

Table 3. The five commonest species in forest and RAF, in Bungo district, Jambi

Land Uses	Understory	Seedling	Sapling	Tree	
Forest	1	<i>Selaginella ornata</i>	<i>Spatholobus sp.1</i>	<i>Acronychia porteri</i>	<i>Alangium javanicum</i>
	2	<i>Phacelophrynium matinum</i>	<i>Syzygium splendens</i>	<i>Actinodaphne glabra</i>	<i>Alseodaphne sp.</i>
	3	<i>Arenga obtusifolia</i>	<i>Gleichenia microphylla</i>	<i>Aglaia forbesii</i>	<i>Alstonia angustifolia</i>
	4	<i>Calamus ciliaris</i>	<i>Urophyllum ferrugineum</i>	<i>Aglaia lawii</i>	<i>Antidesma montanum</i>
	5	<i>Calamus javensis</i>	<i>Ixora brunonis</i>	<i>Ancistrocladus tectorius</i>	<i>Aporosa nervosa</i>
RAF	1	<i>Buettnera curtisii</i>	<i>Fordia splendidissima</i>	<i>Adina dumosa</i>	<i>Hevea brasiliensis</i>
	2	<i>Selaginella ornata</i>	<i>Hevea brasiliensis</i>	<i>Agelaea macrophylla</i>	<i>Artocarpus integer</i>
	3	<i>Selaginella intermedia</i>	<i>Symplocos cochinchinensis</i>	<i>Alseodaphne nigrescens</i>	<i>Macaranga trichocarpa</i>
	4	<i>Taenitis blechnoides</i>	<i>Clidemia hirta</i>	<i>Ancistrocladus tectorius</i>	<i>Parkia sumatrana</i>
	5	<i>Scleria purpuracens</i>	<i>Urophyllum corybosum</i>	<i>Antidesma cuspidatum</i>	<i>Parkia speciosa</i>

4. 'Shadow species' in the forest and RAF

With our limited sample size, many species were observed only once (singletons) within or across land use types. The Rennols-Laumonier equation for 'shadow species' estimated species richness of the forest + RAF data as close to (but not numerically identical) to that of the sum of the forest and RAF alone plus species observed in both RAF and forest (Table 4); species observed at least once in both RAF and forest were doubletons (or higher k-tons) and consequently represented a small number of shadow species. The estimated number of shadow species was 34.4 and 33.5% of the number of observed species, for forest and RAF, respectively, and 2.7% for species observed in both LUT's.

Table 4. Number of observed and shadow (estimated) species observed only in forest, only in RAF, in both forest and RAF, and in the combined data set.

Stratum		Number of species observed in			
		Union Forest+RAF	Forest only	RAF only	Forest+RAF
Trees	Observed	164	99	44	21
	Shadow	69	46	20	2
Saplings	Observed	200	84	76	40
	Shadow	66	32	32	1
Seedlings	Observed	244	91	93	60
	Shadow	61	29	30	1
Understories	Observed	97	24	45	28
	Shadow	21	8	13	0

5. Distribution of early and late successional species

To describe the distribution of the successional status of the species in each stratum in forest and RAF, we compared the cumulative frequency of wood density of the plant species observed (Figure 4). The lowest wood density of species observed in the plots is 250 kg m⁻³ (*Trichospermum javanicum*) and the highest is 1100 kg m⁻³ (*Dialium patens*). The cumulative frequency of wood density had a similar pattern within all strata in RAF and forest.

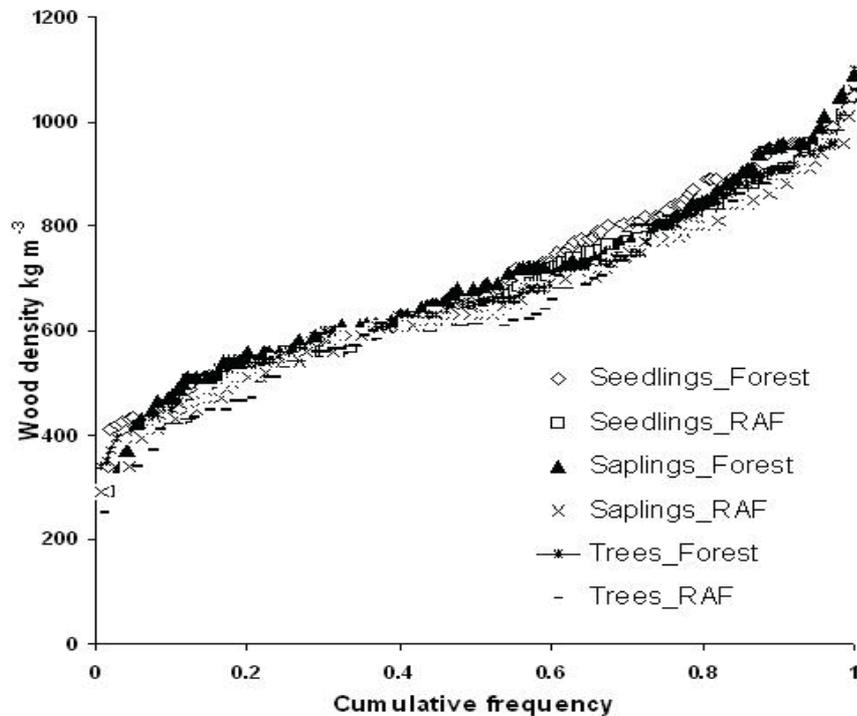


Figure 4. Cumulative frequency of wood density of species found in forest and RAF in three strata, as indicator of successional status

6. Tree dependency on EM and trees with edible parts

Three families with EM dependency were found in Bungo area, e.g. *Dipterocarpaceae*, *Fagaceae* and *Gnetaceae*. The relative abundance in terms of species numbers is shown in Table 5.

Species dependent on EM in the three strata (seedlings, saplings and trees) were more abundant in forest than in RAF. Occurrence of seedlings and trees was significantly different, based on a χ^2 - test (χ^2 was 12.1 and 19.8; with probabilities of 0.01 and 0.001, respectively), while the occurrence of EM dependence in saplings was on the margin of statistical significance significantly different ($\chi^2 = 5.4$; probability 0.05).

Table 5. Relative abundance of species with EM dependency and trees with edible parts in forest and RAF, Bungo district, Jambi.

Relative abundance (%)	Land uses	Stratum		
		Seedlings	Saplings	Trees
EM dependency	Forest	2.8*	5.3	10.6**
	RAF	0.6	1.7	0.5
Tree species with edible parts	Forest	14.3	18.3	28.8**
	RAF	11.7	12.9	64.0

Note : * value in the same column indicates significant difference at $p = 0.01$; ** at $p = 0.001$

The relative abundance of trees with edible parts among seedlings and saplings in forest seemed higher than in RAF, but this difference was not statistically significant (χ^2 were 2.4 and 3.3, for seedlings and saplings, respectively). However, trees with edible parts are far more abundant in RAF than in forests ($\chi^2 = 51.5$; probability 0.001) (Table 5).

B. DISCUSSION

The high floristic diversity of the lowland tropical forests of Sumatra means that the sample size in a study of this size is insufficient to account for the species richness and diversity (Plotkin *et al.*, 2000; Kindt *et al.*, 2006) or presence of rare species with high priority for conservation planning programs (Rennolls and Laumonier, 2006).

Rennolls and Laumonier (2006) reported a total of 499 observed species and an estimated number of 'shadow species' of 175 trees in a 3-ha area in Batang Ule, Jambi. Their ratios of shadow to observed tree species (0.35) was only slightly lower than the ratios we found (0.47 and 0.46 for forest and RAF, respectively), despite the lower absolute numbers. The larger data set of Rasnovi (2006) that included the sapling stratum only for RAF and forests in the Bungo and neighbouring districts of Jambi includes a total species count of 930, in 108 sample plots. If we can assume that the taxonomic skill involved in the different surveys is comparable (and all refer to the Bogor Herbarium as source of knowledge in this regard), it seems likely that the total number of species encountered keeps increasing with sample effort. The 'shadow species' estimate of Rennolls and Laumonier (2006) provides a substantial underestimate of what can be expected for increased sample effort and is not a reliable indicator.

Closer analysis of the forest – RAF comparison showed only slight differences in understory vegetation, seedlings and saplings, indicating high

plant regeneration potential of the RAF. As most of the RAF occurs outside of a direct forest neighbourhood, access is probably highest for plants with seed dispersal by wind (anemochory) or animals (zoochory). Rasnovi (2006) reported that about 71 % of the seedlings observed only in RAF belong to long-range zoochorous species. Expressed as fraction of the species pool, she found that far-zoochory was the dispersal mode of 27.9 and 31.3 % of species observed in forest and RAF, respectively, while autochory (large seeds with limited dispersal range) was represented by 35.1 and 23.1 % of species. These differences in ecological signature should be taken into account, despite the overall numerical similarity of RAF and forest regeneration patterns.

The tree composition of RAF as agroecosystem managed by farmer differed significantly from that of the forest. Tree diversity and species richness in RAF were lower than in forest. In the RAF, non rubber trees, such as food and cash crops grow spontaneously. After the seedling and sapling stage (where forests and RAF are similar), the farmers selectively remove trees that don't have economic or use value, before the time for tapping rubber (about 6-8 year after planting rubber). Farmers maintain (and occasionally transplant) species of non timber products, such as latex, resin, fruits, rattan, for instance, since they can easily harvested the products (Michon, 2005). Rasnovi (2006) found that the intensity of management within RAF had a negative correlation with species richness and similarity of composition with forest. She classified three groups of rubber management, namely (i) high intensity of rubber management or intensive-productive is that rubber trees are being tapped and rubber proportion to other trees is more than 60%; (ii) moderate intensity of rubber management or extensive-productive determined as rubber trees are being tapped and rubber proportion to other trees is less than 60%; (iii) unmanaged is an abandoned RAF and rubber trees have not been tapped. Our observation showed that seedlings and saplings stage were not being tapped yet and had less human intervention, hence species richness of both stages in RAF and forest were similar.

Relative to the total vegetation, plants with edible parts were more abundant in RAF than in forest. Although several plants with edible parts have moderate to high wood density, the cumulative frequency distribution of wood density indicates a slight shift towards early successional plants in RAF (Figure 4). So far, farmers in Bungo have not been interested to plant and maintain timber trees in RAF, as other sources of timber were accessible to them. This, however, may be changing now, as indicated by farmer interest in enrichment planting with timber. The frequency of trees dependent on EM was less in RAF than in forest. Tree dependency on EM is common in late successional species that produce good timber, except for the family of *Gnetaceae*, which is well known as tree with edible part (fruits and leaves), i.e. *Gnetum gnemon*. We encountered

liana *Gnetum* sp., *G. cuspidatum* and *G. latifolium* in the forest plots that were grouped as understory stage.

Most *Dipterocarpaceae* have large seeds and short-range dispersal, which may hinder spontaneous regeneration in RAF far away from forest. Therefore dipterocarp regeneration in RAF may require enrichment planting, if farmers become interested in and receive economic incentives for more diverse and forest-like species composition of RAFs. Evidence so far indicates that the RAFs represent an ecological ‘tipping point’ – they still allow for ecological restoration of lowland forest diversity if management intensity is reduced, but they are already depleted in species of late successional signature.

IV. CONCLUSIONS

RAF has considerable species richness in the strata of seedling and sapling. The species richness and diversity index in RAF decrease in tree strata, due to human intervention for rubber management. The relative distribution of early and late successional species as evident from the wood density distribution, however, showed no difference between RAF and forest.

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REFERENCES

- Beukema, H.J. and M. van Noordwijk. 2004. Terrestrial pteridophytes as indicators of a forest-like environment in rubber production systems in the lowlands of Jambi, Sumatra. *Agriculture Ecosystems and Environment* 104: 63-73.
- Beukema, H., F. Danielsen, G. Vincent, S. Hardiwinoto, and J. van Andel. 2007. Plant and bird diversity in rubber agroforests in the lowlands of Sumatra, Indonesia. *Agroforestry System* 70: 217-242.

- FWI/GFW. 2001. Keadaan hutan Indonesia. Bogor, Forest Watch Indonesia, Indonesia and Global Forest Watch, Washington, D.C.
- Giller, K.E., D.E. Bignell, P. Lavelle, M.J. Swift, E. Barrios, F. Moreira, M. van Noordwijk, I. Barois, N. Karanja, and J. Huising. 2005. Soil biodiversity in rapidly changing tropical landscapes: scaling down and scaling up. *In*: M.B. Usher, R. Bardgett, and D.W. Hopkins (Eds.) *Biological Diversity and Function in Soils*. Cambridge University Press, Cambridge, the U.K. pp. 295-318.
- Gillison, A.N. and N. Liswanti. 2004. Assessing biodiversity at landscape level in Northern Thailand and Sumatra (Indonesia): the importance of environmental context. *Agriculture, Ecosystems and Environment* 104: 75-86.
- Gouyon, A., H. de Foresta, and P. Levang P. 1993. Does 'Jungle Rubber' deserve its name? An analysis of rubber agroforestry system in Southeast Asia. *Agroforestry Systems* 22: 181-206.
- Joshi, L., G. Wibawa, H.J. Beukema, S.E. Williams, and M. van Noordwijk M. 2003. Technological change and biodiversity in the rubber agroecosystem. *In*: J.H. Vandermeer (Ed.) *Tropical Agroecosystems: New Directions for Research*. CRC Press, Boca Raton, Florida, the U.S.A. pp. 133- 157.
- Joshi, L. M. van Noordwijk, and F.R.L. Sinclair. 2005. Bringing local knowledge in perspective: A case of sustainable technology development in jungle rubber agroforests in Jambi, Indonesia. *In*: A. Neef (Ed.) *Participatory Approaches for Sustainable Land Use in Southeast Asia*. White Lotus Press, Bangkok. pp. 277-289.
- Kessler, P.J.A and K. Sidiyasa. 1994. Trees of the Balikpapan-Samarinda area, East Kalimantan, Indonesia: A manual to 280 selected species. Tropenbos Series. 7. Tropenbos Foundation. Den Haag, the Netherlands.
- Kindt, R. and R. Coe. 2005. Tree diversity analysis: A manual and software for common statistical methods for ecological and biodiversity studies. World Agroforestry Centre (ICRAF). Nairobi, Kenya.
- Kindt, R., P. van Damme, and A.J. Simons. 2006. Patterns of species richness at varying scales in Western Kenya: planning for agroecosystem diversification. *Biodiversity Conservation*. DOI: 10.1007/s10531-005-0311-9
- Laumonier, Y. 1997. The vegetation and physiography of Sumatra. Kluwer, Dordrecht, the Netherlands.
- Lee, S.S. 1998. Root symbiosis and nutrition. *In*: S. Appanah and J.M. Turnbull (Eds.) *A Review of Dipterocarps: Taxonomy, Ecology and Silviculture*.

- CIFOR and FRIM. Center for International Forestry Research. Bogor, Indonesia. pp: 99-114.
- Ludwig, J.A. and J.F. Reynolds. 1988. *Statistical Ecology: a primer on methods and computing*. John Wiley & Sons, Inc. Canada.
- Michon, G. 2005. *Domesticating forests: How farmers manage forest resources*. Institut de recherché pour le Développement (IRD), Center for International Forestry Research (CIFOR) and World Agroforestry Centre (ICRAF), Bogor, Indonesia.
- Murdiyarso, D., M. van Noordwijk, U.R. Wasrin, T.P Tomich, A.N. Gillison. 2002. Environmental benefits and sustainable land-use options in the Jambi transect, Sumatra, Indonesia. *Journal of Vegetable Science* 13: 429-438.
- Plotkin, J., B. Potts, M.D. Douglas, W. Yu, S. Bunyavejchewin, R. Condit, R. Foster, S. Hubble, J. La Frankie, N. Manokaran, H..S. Lee, R. Sukumar, M.A. Nowak, and P.S. Ashton. 2000. Predicting species diversity in tropical forests. *PNAS* 97: 10850-10854.
- Rasnovi, S. 2006. *Ekologi regenerasi tumbuhan berkayu pada sistem agroforest karet*. Sekolah Pasca Sarjana, Institut Pertanian Bogor. Bogor, Indonesia. Dissertation (in Bahasa Indonesia with English abstract).
- Rennolls, K. and Y. Laumonier. 2006. A new local estimator of regional species diversity, in terms of 'shadow species', with a case study from Sumatra. *Journal of Tropical Ecology* 22: 321-329.
- Roos, M.C., P.J.A. Kessler, S.R. Gradstein, and P. Baas. 2004. Species diversity and endemism of five major Malesian Islands: diversity-area relationships. *Journal of Biogeography* 31: 1893-1908.
- Schmidt, F.H. and J.H.A. Ferguson. 1951. Rainfall types on wet and dry period ratios for Indonesia with Western New Guinea. *Verhandelingen No. 42 Kementrian Perhubungan Djawatan Meteorologi*.
- Smits, W.T.M. 1994. *Dipterocarpaceae: Mycorrhiza and Regeneration*. Tropenbos Series 9. Tropenbos Foundation. Den Haag.
- Susilo, F.X., A.M. Neutel, M. van Noordwijk, K. Hairiah, G. Brown, and M.J. Swift. 2004. Soil biodiversity and food webs. *In*: M. van Noordwijk, G. Cadisch, and C.K. Ong (Eds.) *Belowground interactions in tropical agroecosystems*, CAB International, Wallingford, the U.K. pp: 285-307
- Swaine, M.D. and T.S. Whitmore. 1988. On the definition of ecological species groups in tropical forests. *Vegetation* 75: 81-86.

- Swift, M.J., A.M.N. Izac, and M. van Noordwijk. 2004. Biodiversity and ecosystem services in agricultural landscapes: Are we asking the right questions? *Agriculture Ecosystems and Environment* 104: 113-134.
- Tomich, T.P., H. de Foresta, R. Dennis, Q.M. Ketterings, D. Murdiyarso, C.A. Palm, F. Stolle, S. Suyanto, and M. van Noordwijk. 2002. Carbon offsets for conservation and development in Indonesia? *American Journal Alternative Agriculture* 17: 125-137.
- Van Noordwijk, M., D. Murdiyarso, K. Hairiah, U.R. Wasrin, A. Rachman, T.P. Tomich. 1998. Forest soils under alternatives to slash-and-burn agriculture in Sumatra, Indonesia. *In*: A. Schulte and D. Ruhayat (Eds.). *Soils of Tropical Forest Ecosystems: Characteristics, Ecology and Management*. Springer-Verlag, Berlin. pp: 175-185.
- Wang, B. and Y.L. Qiu. 2006. Phylogenetic distribution and evolution of mycorrhizas in land plants. *Mycorrhiza* 16: 299-363.
- Whitmore, T.C. 1983. *Tree Flora of Malaya: a manual for forester*. Vol: 1-4. The Forest Research Institute Kepong. Forest Department. Ministry of Agriculture and Lands, Malaysia.
- Whitmore, T.C. and I.G.M. Tantra. 1986. *Tree Flora of Indonesia: Check list for Sumatra*. Forest Research and Development Centre. Bogor, Indonesia.