The impact of sustainable forest management on plant and bird diversity in East Kalimantan, Indonesia

Arbainsyah, A.

2

Structure, composition and diversity of plant communities, selectively logged forests of different ages compared to primary rain forest

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Arbainsyah, H.H. de Iongh, W. Kustiawan & G.R. de Snoo

Abstract

The impact of logging on plant communities was studied in forest that has been logged selectively 1, 5 and 10 years previously (in the process of certified): diversity was compared with that of primary rain forest in the Berau region of East Kalimantan, Indonesia. Four sets of 20 transects located within an area of 6 ha were sampled for all trees, saplings and seedlings, and records were made of topographic position, structure, composition and species diversity. There was a high level of floristic similarity between primary forests at the study sites compared to primary forest elsewhere in Kalimantan. The impact of logging is therefore likely to be the most important factor determining any differences between the plant communities of the selectively logged and primary forest sites. We found differences in species composition and abundance of most plants between selectively logged and primary forest. Overall, stem densities of trees in the primary forest were higher than in the three selectively logged forest sites. Stem densities of saplings were equivalent in all four forests. Seedling stem densities were higher in the forest site logged 10 years previously than in primary forest. Our results showed that the forests logged selectively under certified regimes still have a high plant diversity, possibly indicating that biodiversity values may be conserved by following certification procedures.

Key words: Sustainable forest management, Selective logging, Species diversity, Forest structure, Tropical rain forest.

Introduction

Tropical rain forests are recognized for their high biological diversity and their ecosystem services (Richards, 1952; Whitmore, 1984; Sheil & Van Heist, 2000; Jennings *et al.*, 2001). Large parts of East Kalimantan are now covered by forests that are degraded as a result of fire and logging (Slik *et al.*, 2002; van Nieuwstadt 2002; Meijaard *et al.*, 2005; Eichhorn *et al.*, 2006). Forest certification (Lembaga Ekolabel Indonesia-LEI and the Forest Stewardship Council-FSC) has been introduced in Indonesia since several decades. The impact of FSC-certified logging on biodiversity has rarely been quantified, however (Van Kuijk *et al.*, 2009). There is a need to develop suitable biological indicators of sustainable forest management at the forest management unit level (Ghazoul & Hellier 2000; De Iongh & Van Weerd, 2006; De Iongh & Persoon, 2010).

Commercial logging leads to fragmentation and degradation of the remaining tropical rain forests (Kartawinata, 1977; Skole & Tucker, 1993; Parthasarathy *et al.*, 1999), and results in many processes negatively affecting populations of plants and animals. When basic biological characteristics of the commercial species are considered in timber harvesting prescriptions, mixed dipterocarp forests appear capable of sustained timber yield in combination with habitat conservation. The Indonesian selective logging system allow selective logging intensity of ≥ 8 trees/ha associated with a felling cycle of 40–60 years depending on site conditions (Sist *et al.*, 2003; Van Kuijk *et al.*, 2009). It has been more than 10 years since parts of the forest were selectively logged in the initial exploitation period in the 2000s (Kuswandari, 2004). Intermediate disturbance hypothesis is one of the most frequently suggested non-equilibrium explanations for maintaining species diversity in all communities (Connell, 1978; Wilson, 1990; Roxburgh *et al.*, 2004).

Tree mortality in the understorey of logged forest is at least 2–3 times lower than in the forest overstorey, and mostly occurs near and on skid trails (Webb, 1998; Woods, 1998; Pinard *et al.*, 2000; Slik *et al.*, 2002). In addition, some light-demanding, non-pioneer species may exhibit higher growth rates after logging. The increased light levels in the understorey of logged forests result in the rapid growth of many herbaceous and woody pioneer species (Woods, 1998; Fredericksen & Mostacedo, 2000). Trees make up only a part of the tropical rain forest ecosystem; herbs, shrubs, ferns and lianas generally constitute a large component of total plant diversity (Eichhorn *et al.*, 2006; Yassir *et al.*, 2010). To evaluate its biodiversity it is very important to know the vegetation composition of a forest type, from canopy to forest floor including trees, climbers (liana and rattan),

non-rattan (Palmae), herbs, shrubs, etc., all of which are genetic resources for plant species within the forest.

Many impacts of logging have been studied; tree mortality in the forest overstorey (diameter at breast hight (dbh) ≥ 10 cm) (Slik *et al.*, 2002; Van Nieuwstadt, 2002), the mortality of canopy trees due to edge effects (Laurance et al. 2000), recruitment failure resulting from over-predation of seeds (Curran *et al.*, 1999; Eichhorn *et al.*, 2006), reduced seedling establishment and plant growth (Slik, 2001; Bruna *et al.*, 2002; Bruna, 2003), local extinction of plants (Benitez-Malvido & Martinez-Ramos, 2003), decline in butterfly abundance and/or diversity (Cleary, 2002), decline in bird abundance and/or diversity (Boulinier *et al.*, 2001; Beier *et al.*, 2002; Slik & Van Balen 2006), and decreased pollination (Ashworth *et al.*, 2004). Logging also often leads to an increase in local human populations and to increased accessibility of the forest (Kartawinata & Vayda, 1984), which in turn results in increased illegal logging and hunting and a decrease in biodiversity of remaining forest fragments (Laurance, 1998; Hartshorn & Bynum, 2001; Curran *et al.*, 2004). The final outcome may be local mass extinctions of species as has been recently documented for Singapore (Brook *et al.*, 2003). Because tropical rain forests harbour most of the world's biodiversity, tropical deforestation has become the major cause of global species extinctions (Pimm & Raven, 2000).

The main goal of our research is to quantify the impact of selectively logged forest in the process of FSC certification on botanic diversity and forest structure of tropical lowland forest in Borneo. Here we present the results of a detailed study of selectively logged forests (in the process of FSC certification) and primary rain forest site in the Indonesian province of East Kalimantan, including all terrestrial vascular plants. The three logged forest plots had been logged 1, 5 and 10 years ago. We analysed the structure and composition of forest plots under different logging regimes by assigning species to life forms that can be readily applied in the field (e.g., Eichhorn *et al.*, 2006). We assessed the impact of selective logging at the landscape level to ensure that our plant diversity assessment was representative for the large scale at which disturbance by logging activities occurs. The numbers were expected to reflect the scale and severity of the disturbances taking place in a large forest area (Primack & Lee, 1991; Davies *et al.*,1998; Slik *et al.*, 2002), and as such could be useful to estimate the impact of logging on future plant diversity. Finally, we address what are the differences in vegetation structure and composition in selectively logged forest sites in comparison to primary forest?

Materials and methods

Study area

The study area is located in a lowland forest within the forest concession of PT. Hutansanggam Labanan Lestari (HLL) Labanan, East Kalimantan. The largest share of the new company area belong to the state-owned logging company of PT. Inhutani I (in the process of FSC certification), in Berau district, in the northeastern part of the Indonesian province of East Kalimantan (Figure 2.1). This concession is in the process of being FSC certified. The elevation range at the study area is 25 to 140 m above sea level. The topography consists of a rolling hilly landscape with shallow valleys and gullies, the highest elevation being 140 m. The soils consist of loamy clay and sandy soils with a top soil layer of approximately 5-10 cm (Mantel *et al.*, 2002).

Sites were established in primary forest (1 site) and selectively logged forest (3 sites) (Figure 2.1). In these plots, three groups of plants (trees, saplings and seedlings) were systematically recorded along a line transect of 10 × 300 m. In total, 20 transects were sampled, 5 in primary forest and 5 in each of the 3 selectively logged over forest. We divided each line transect into 30 plots of 10 × 10 m (a total of 150 plots in each site) to measure all trees with a dbh ≥ 10 cm (dbh. 130 m above ground level or, if buttresses are present, 30 cm above buttresses) using the circumference method. Within each plot, a subplot of 5 × 5 m for saplings and 2 × 2 m for seedlings were established and measured (number of individuals per species and cover estimate). These measurement quadrats for seedlings and saplings were positioned alternately to the left and right of transect centre lines at intervals of 100 m, resulting in 15 subplots per site.

Plants were sampled and identified, i.e. whenever a fertile plant, labeled (vouchers stored in the Herbarium Wanariset Samboja, Indonesia). The field work was done by the principle author, together with field assistants.

Life forms

In order to provide a detailed description of the structure and composition of the terrestrial plant community in the four research sites, all species were assigned to life forms and taxonomic criteria (Table 2.1). The criteria used were chosen in such a way that they provided maximum information about the forest structure and composition while still being applicable for para-taxonomists in comparative studies in East Kalimantan and elsewhere in the tropics (Eichhorn *et al.*, 2006). To enhance compatibility with growth forms that were used in similar studies

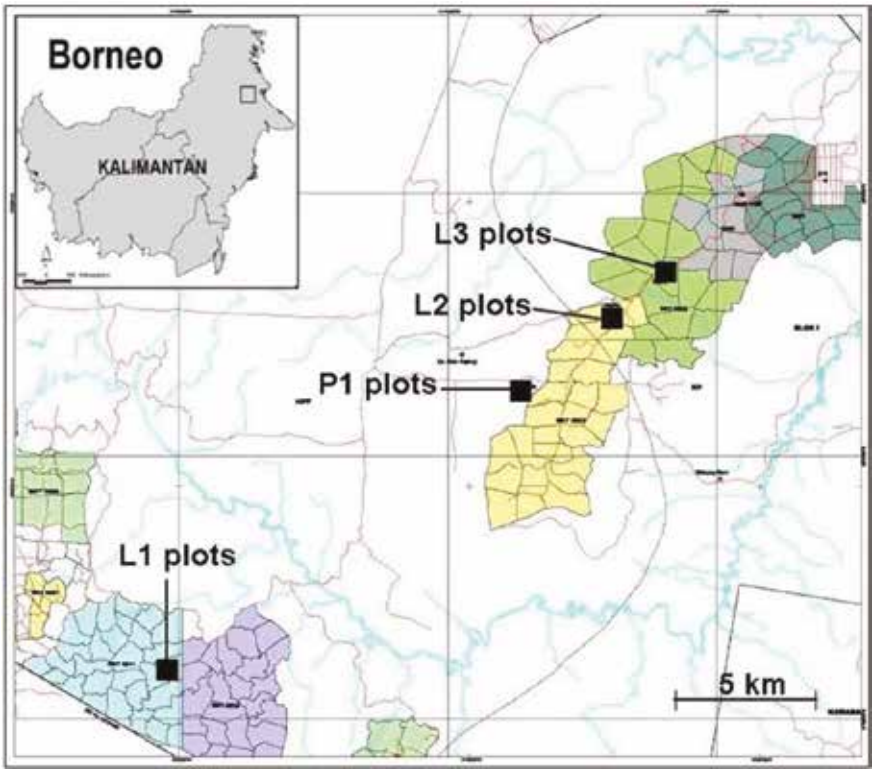

Figure 2.1
Map of East Kalimantan with the location of study areas P1 plots: primary forest site, L1 plots: forest site logged 1 year ago (2011), L2 plots: forest site logged 5 years ago (2007), L3 plots: forest site logged 10 years ago (2003).

in the past, species were first assigned to three major groups: trees, saplings and seedlings. Several life forms were distinguished within these three major groups, based on taxonomic criteria and growth form. Throughout this study, each plant species was assigned referred to one of the following three life forms.

1. *Trees* defined as non-climbing woody species of which the mature individuals had a stem diameter ≥ 10 cm.
2. *Saplings* defined as all herbaceous species, non-climbing woody species and climbing woody species of which the mature individuals had a stem diameter ≤ 10 cm and were on average more than 1.5 m tall.
3. *Seedlings* defined as all herbaceous species, non-climbing woody species and climbing woody species of which the mature individuals were on average less than 1.5 m tall.

Table 2.1
List of the life forms used in this study and the taxa, growth form and size class they represent.

Life Form	Taxa	Growth form and size
Trees (woody non-climbers with stem diameter ≥ 10 cm)		
Palms - trees	Palmae	woody non climbers, height >1.3 m
Dicots – trees	Dicotyledonae	woody non climbers, height >1.3 m
Saplings (herbs, shrubs, climbers, woody non-climbers with diameter < 10 cm)		
Monocots - other herbs	Monocotyledonae	herbaceous non climbers, height >1.5 m
Dicots - trees	Dicotyledonae	woody non climbers, height >1.5 m
Dicots - lianas	Dicotyledonae	climber, height >1.5 m
Dicots - shrubs	Dicotyledonae	woody non climbers, with many branches from the ground, height >1.5 m
Seedlings (herbs, shrubs, climbers, woody non-climbers < 1.5 height		
Palms - lianas (rottans)	Palmae	climber, height <1.5 m
Palms - palmlets	Palmae	woody non-climber, height <1.5
Monocots - small lianas	Monocotyledonae	climber, height <1.5 m
Monocots - other herbs	Monocotyledonae	herbaceous non climbers
Monocots - grass-like	Graminae+Cyperaceae	herbaceous, leaves linear
Dicots - small treelets	Dicotyledonae	woody non-climber, height <1.5
Dicots - small lianas	Dicotyledonae	climber, height <1.5 m
Dicots - small shrubs	Dicotyledonae	woody non-climber, with many branches from the ground, height <1.5
Ferns - small lianas	Filicopsida	climbers
Ferns - herbs	Filicopsida	herbaceous non climbers

Data analyses and statistics

All data analyses were performed with Microsoft Excel and SPSS 13.0 software to calculate standard deviation for the estimated average number of stems. Tree species diversity of the plots was compared between of selectively logged forests, and primary forest. These comparisons were made to compensate for differences in sample sites between of selectively logged forests in comparison to primary forest. Post hoc comparisons between of selectively logged forests, and primary forest were made using the Fisher's Least Significant test (one-way ANOVA based on ln transformed data, with Bonferroni multiple comparison test). The stages in evaluating the data were as follows:

1 Counting the number of stems of all trees, saplings and seedlings found in each transect.

2 Calculating Species Diversity Index (H), Evenness Index (E) and Dominance Index (C).
Species diversity analysis was done with the Shannon Diversity Index, with the Jost (2006) formula as follows:

Diversity Index $$H = \sum_{S=1}^{S} p_i \ln p_i$$

where H is the Shannon Diversity Index, S is the total number of species in the community, pi is the proportion of abundance of the i species. pi is calculated by dividing the number of species i by the total number of all species. Then to determine the Evenness Index (E) the Pielou Evenness Index (Ludwig & Reynolds, 1998) formula was used:

Evenness Index (E) = ∑ H/ln(S)

where E is the Pielou Evenness Index, ln is the normal logarithm, S number of species.
The Dominance Index (C) was determined using the formula:

Dominance Index (C) = ∑ $(ni/N)^2$

where C is the Dominance Index, ni is the number of individuals of a certain species, N is the total number of individuals of all species.

3 Calculating the estimated average number of stems (N) and stems per hectare (q) for each class (trees, saplings and seedlings) Ludwig and Reynolds (1998):

$$q = \frac{\sum_{i=1}^{n} Yi}{\sum_{i=1}^{n} Xi}$$

where q is the average number of stems (N) per hectare, Yi is the Number of stems (N) per hectare of given transect, Xi is the area of a given transect.

4 Calculating the Importance Value index (I.V.) for each level/strata. The formula used in calculating I.V. was the quadrate method (Mueller-Dombois & Ellenberg, 1974). The (I.V.) of species is defined as sum of its relative density

(RD), relative dominance (Rd) and relative frequency (RF) (I.V.) = RD + RF + Rd), which are calculated using the following equations:

$$\text{Density (D)} = \frac{\text{Number of individuals of a species}}{\text{Area of all sample units}}$$

$$\text{Relative Density (RD)} = \frac{\text{Number of individuals of a species}}{\text{Density for all species}} \times 100\%$$

$$\text{Frequency (F)} = \frac{\text{Number of quadrats containing a certain species}}{\text{Total number of quadrats}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a certain species}}{\text{Total number of species}} \times 100\%$$

$$\text{Dominance (d)} = \frac{\text{Basal area of a species}}{\text{Area of all sample units}}$$

$$\text{Relative Dominance (Rd)} = \frac{\text{Dominance of one species}}{\text{Dominance of all species}} \times 100\%$$

The Importance Value index for trees and saplings was calculated based on the formula:

$$\text{Importance Value index (I.V.)} = RD + RF + Rd$$

For seedling levels, the species importance value index was calculated using the formula:

$$\text{Importance Value index (I.V.)} = RD + RF$$

Results

Composition and biodiversity in selectively logged and primary forests

Tree diversity was higher in the forest site logged selectively 1 year ago, where $H > 4.5$, but the dominance index and number of stems were almost as high in the primary forest site (Table 2.2). This high dominance index is indicated by the very abundant tree species of *Hopea semicuneata*, with an I.V. score of 43.4% (Table 2.6). In contrast to the tree diversity index, the highest evenness index was

found in the forest site logged 1 year ago, with a total of 156 species encountered (Table 2.3).

Sapling diversity was higher in the primary forest site compared to selectively logged forest sites, but the dominance index of the forest site logged 5 years ago was higher than that of the other forest sites (Table 2.2). This high dominance is indicated by regenerating species of *Madhuca malaccensis*, with an I.V. score of 25.5%, two times more dominant than other species (Table 2.7). In contrast to the saplings diversity index, the highest evenness index was found in primary forest with a total number of 97 species encountered (Table 2.4).

Seedling diversity was high in some of the selectively logged forest sites, in the forest site logged 1 year ago, but due to the dominance index was found in primary forest site (Table 2.2). This dominance was indicated by the very abundant species of *Hopea semicuneata,* with an I.V. score of 24.6%, which is also the highest in the regeneration of saplings and trees (Table 2.7 and 2.8). In contrast to the seedlings diversity index, the highest evenness index was found in the forest site logged 1 year ago, with a total number of 95 species encountered (Table 2.5).

Table 2.2
Comparison between the diversity index (H), dominance index (C), evenness index (E) and number of stems for all trees (dbh ≥ 10 cm) per 1.5 ha, all saplings (dbh < 10 cm) per 0.375 ha and all seedlings in ground cover per 0.06 ha in primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

Index	Primary forest	Selectively logged Forest		
		1 year ago	5 years ago	10 years ago
Tree (1.5 ha)				
▪ Diversity (H)	4.259	4.509	4.339	4.260
▪ Dominance (C)	0.033	0.019	0.023	0.022
▪ Evenness (E)	0.853	0.893	0.879	0.888
▪ Number of stems	612	492	501	558
Sapling (0.375 ha)				
▪ Diversity (H)	4.352	4.175	4.095	4.150
▪ Dominance (C)	0.015	0.020	0.024	0.023
▪ Evenness (E)	0.951	0.937	0.922	0.918
▪ Number of stems	245	247	242	244
Seedling (0.06 ha)				
▪ Diversity (H)	4.067	4.319	4.090	4.217
▪ Dominance (C)	0.030	0.017	0.025	0.020
▪ Evenness (E)	0.908	0.948	0.913	0.930
▪ Number of stems	328	306	303	346

Table 2.3
Comparison between the abundance and species richness (average ± standard deviation) for all trees (dbh ≥ 10 cm) life form and forest sites.

Trees	Abundance stems (per 100 m²)				Species per subplot (10 × 10 m)				Total species number			
	Primary forest	Selectively logged forest			Primary forest	Selectively logged forest			Primary forest	Selectively logged forest		
		1 year ago	5 years ago	10 years ago		1 year ago	5 years ago	10 year ago		1 years ago	5 years ago	10 years ago
Life form												
▪ Palms - trees	0.00 ± 0.00	0.05 ± 0.29	0.00 ± 0.00	0.02 ± 0.25	0.00 ± 0.00	0.04 ± 0.19	0.00 ± 0.00	0.01 ± 0.08	0	1	0	1
▪ Dicots - trees	4.08 ± 1.97	**3.23 ± 2.13**	**3.34 ± 2.08**	3.70 ± 1.86	3.70 ± 1.78	3.30 ± 1.67	3.19 ± 1.79	3.49 ± 1.62	147	155	139	120
Total	4.08 ± 1.97	**3.28 ± 2.15**	**3.34 ± 2.08**	3.72 ± 1.87	3.70 ± 1.78	3.33 ± 1.70	3.19 ± 1.79	3.49 ± 1.62	147	156	139	121

Abundance expressed as densities of stems exceeding 1.3 height. Species richness at the subplot scale expressed as species number per subplot and at the landscape scale as the total observed species numbers in all subplot together in primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago, in plot of 10 × 10 m, in total of 1.5 ha. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests)

Table 2.4
Comparison between the abundance and species richness (average ± standard deviation) for all saplings (dbh < 10 cm) life form and forest sites.

Saplings	Abundance stems ((per 25 m²)				Species per subplot (5 x 5 m)				Total species number			
	Primary forest	Selectively logged forest			Primary forest	Selectively logged forest			Primary forest	Selectively logged forest		
		1 year ago	5 years ago	10 years ago		1 year ago	5 years ago	10 years ago		1 years ago	5 years ago	10 years ago
Life form												
▪ Monocots - herbs	0.00 ± 0.00	0.13 ± 0.52	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0	1	0	0
▪ Dicots - treelets	16.27 ± 4.11	15.80 ± 6.19	15.40 ± 5.26	15.60 ± 3.58	12.93 ± 3.01	9.40 ± 3.14	11.93 ± 4.20	10.40 ± 4.10	96	83	84	89
▪ Dicots - lianas	0.00 ± 0.00	0.40 ± 1.55	0.00 ± 0.00	0.33 ± 1.29	0.00 ± 0.00	0.07 ± 0.26	0.00 ± 0.00	0.13 ± 0.52	0	1	0	2
▪ Dicots - shrubs	0.06 ± 0.26	0.13 ± 0.35	0.73 ± 1.16	0.33 ± 0.72	0.07 ± 0.26	0.13 ± 0.35	0.40 ± 0.51	0.20 ± 0.41	1	1	1	1
Taxa												
▪ Monocots	0.00 ± 0.00	0.13 ± 0.52	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0	1	0	0
▪ Dicots	16.33 ± 4.06	16.34 ± 6.35	16.13 ± 5.88	16.27 ± 4.37	13.00 ± 2.98	9.60 ± 3.18	12.27 ± 4.40	10.73 ± 4.04	97	85	85	92
Total	16.33 ± 4.07	16.47 ± 6.50	16.13 ± 5.88	16.27 ± 4.37	13.00 ± 2.98	9.67 ± 3.13	12.27 ± 4.40	10.73 ± 4.04	97	86	85	92

Abundance expressed as densities of stems exceeding ≥ 1.5 height. Species richness at the subplot scale expressed as species number per subplot and at the landscape scale as the total observed numbers of species in all subplots together in primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago, in plot of 5 x 5 m, in total of 0.375 ha. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni Correction for multiple tests).

Table 2.5
Comparison between the abundance and species richness (average ± standard deviation) for all seedlings life form and forest sites.

Seedlings	Abundance stems (per 4 m²)				Species per subplot (2 × 2 m)				Total species number			
	Primary forest	Selectively logged forest			Primary forest	Selectively logged forest			Primary forest	Selectively logged forest		
		1 year ago	5 year ago	10 year ago		1 year ago	5 year ago	10 year ago		1 year ago	5 years ago	10 years ago
Life form												
▪ Palms - lianas (rottans)	0.80 ± 1.21	0.27 ± 0.46	0.13 ± 0.35	0.13 ± 0.35	0.53 ± 0.74	0.27 ± 0.46	0.13 ± 0.35	0.13 ± 0.35	3	2	2	2
▪ Palms - small trees	0.13 ± 0.52	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	1	1	0	0
▪ Monocots- small lianas	0.07 ± 0.26	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	1	1	0	0
▪ Monocots - herbs	0.07 ± 0.26	0.33 ± 0.72	0.67 ± 1.84	0.13 ± 0.35	0.07 ± 0.26	0.20 ± 0.41	0.20 ± 0.41	0.13 ± 0.35	1	2	2	2
▪ Monocots - grass	0.20 ± 0.56	0.53 ± 1.19	0.00 ± 0.00	0.13 ± 0.52	0.13 ± 0.35	0.27 ± 0.59	0.00 ± 0.00	0.07 ± 0.26	2	2	0	1
▪ Dicots - small trees	18.80 ± 9.22	12.87 ± 6.86	15.80 ± 8.05	18.60 ± 9.91	8.33 ± 2.32	6.87 ± 3.16	8.13 ± 2.64	8.40 ± 3.58	69	67	65	75
▪ Dicots - small lianas	1.67 ± 1.95	**3.33 ± 3.54**	1.93 ± 1.39	**0.80 ± 1.26**	1.00 ± 1.00	**1.47 ± 0.99**	**1.47 ± 1.13**	**0.47 ± 0.74**	9	13	15	6
▪ Dicots - shrubs	0.07 ± 0.26	0.47 ± 0.92	0.13 ± 0.52	0.27 ± 0.46	0.07 ± 0.26	0.20 ± 0.41	0.07 ± 0.26	0.27 ± 0.46	1	3	1	1
▪ Ferns - small lianas	0.07 ± 0.26	0.60 ± 1.59	1.47 ± 3.09	1.20 ± 2.78	0.07 ± 0.26	0.13 ± 0.35	0.20 ± 0.41	0.40 ± 0.83	1	1	2	4
▪ Ferns - herbs	0.00 ± 0.00	1.67 ± 2.23	0.07 ± 0.26	1.80 ± 4.18	0.00 ± 0.00	**0.60 ± 0.74**	**0.07 ± 0.26**	0.27 ± 0.59	0	2	1	2
▪ Ferns - small trees	0.00 ± 0.00	0.20 ± 0.41	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.41	0.00 ± 0.00	0.00 ± 0.00	0	1	0	0
Taxa												
▪ Monocots	1.27 ± 1.39	1.27 ± 1.28	0.80 ± 1.86	0.40 ± 0.74	0.87 ± 0.83	0.87 ± 0.74	0.33 ± 0.62	0.33 ± 0.62	9	8	4	5
▪ Dicots	20.53 ± 8.83	16.67 ± 8.80	17.87 ± 8.24	19.67 ± 9.82	9.40 ± 2.47	8.40 ± 3.91	9.67 ± 2.58	9.13 ± 3.64	78	83	81	82
▪ Ferns	0.07 ± 0.26	2.47 ± 2.83	1.53 ± 3.20	3.00 ± 6.89	0.07 ± 0.26	**1.07 ± 0.96**	0.27 ± 0.59	0.67 ± 1.40	1	4	3	6
Total	21.87 ± 8.84	20.40 ± 9.82	20.20 ± 6.46	23.07 ± 11.20	10.33 ± 2.64	10.33 ± 4.27	10.27 ± 2.34	10.13 ± 3.09	88	95	88	93

Abundance expressed as densities of stems percentage ground cover. Species richness at the subplot scale expressed as species number per subplot and at the landscape scale as the total observed species numbers in all subplot together in primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago, in plot of 2 x 2, in total of 0.06 ha. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests).

Abundance and composition of three major groups of species

Tree densities were significantly lower in the forest sites logged selectively 1 and 5 years ago than in the primary forest site, but tree densities in the forest site logged 10 years ago were similar to those of the primary forest site (Table 2.3). Dicot trees were clearly the dominant tree type, as they accounted for ca. 99% of the stems in all four forest sites. However, palm trees still exceeded densities of 3 stems ha^{-1} in at least one of the four forest sites.

There were no significant differences in sapling densities among all four forests, but due to the dicot shrubs, the total number of stems in the forest site logged 5 years ago was higher than in the other three forest sites (Table 2.4). When the dicot shrubs were excluded from the analysis, stem density in the selectively logged forest, namely of the forest site 5 years ago was 242 stems ha^{-1} this is the lowest when compared to primary forest site, the sites logged 1 year ago and 10 years ago with stem density of 245, 247 and 244 stems ha^{-1}.

There were no significant differences between seedlings, which were in general equally abundant in all four forest sites. Due to the presence of small dicot lianas, the total number of stems in forest sites logged selectively 1 and 10 years ago was significantly greater than in the other forest sites (Table 2.5). Palm lianas were clearly the most abundant life form in primary forest, while small fern lianas and fern herbs were both very abundant in selectively logged forest sites.

Small trees, small lianas, herbs and shrubs all contributed importantly to overall seedling densities, but there were pronounced differences between these growth forms with respect to the forest type (Figure 2.2, Table 2.8). Densities of small tree seedlings were highest in the primary forest site and lowest in the forest sites 1 and 5 years ago with the forest site logged 10 years ago being more or less intermediate. When compared to small liana seedlings, the forest site 1 year ago had value twice that of the primary forest site (Figure 2.2). Densities of both herb and shrub seedlings were almost three times higher in the logged forest sites compared to the primary forest site (Figure 2.2, Table 2.5).

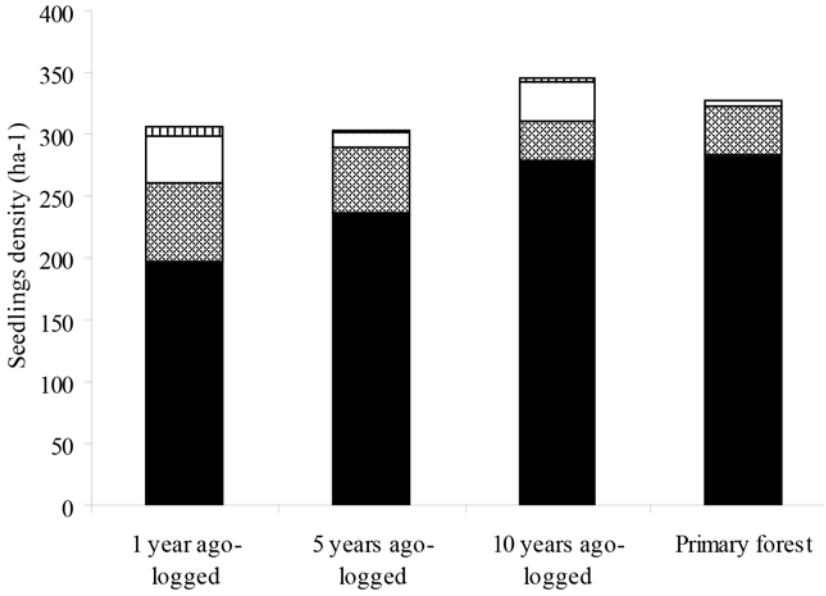

Figure 2.2
Density of seedlings of small trees (solid bars), small lianas (cross-hatched bars), herbs (open bars) and shrubs (horizontal bars) in four forest sites of the primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

Abundance and composition of different types of trees

Dicot trees were significantly less abundant in the forest sites logged 1 and 5 years ago than in the primary forest site, but dicot tree densities in the forest site logged 10 years ago were similar to those of the primary forest site (Tables 2.2 and 2.3). In the primary forest site, the dominant families were Dipterocarpaceae, Euphorbiaceae, Caesalpiniaceae, Burseraceae and Sapotaceae (Table 2.6). Species that contributed greatly to the dominance of these families were *Hopea semicuneata* and *Dipterocarpus lowii* (both Dipterocarpaceae), *Chaetocarpus castanocarpus* (Euphorbiaceae), *Cynometra elmeri* (Caesalpiniaceae) and *Palaquium stenophyllum* (Sapotaceae).

The abundance of tree species of *Hopea* was highest in the primary forest site (Table 2.6), only Dipterocarpaceae were more dominant in the forest site logged 10 years ago than in the primary forest site, while other dominant families of the three selectively logged forest sites were much less abundant compared with the primary forest site (Figure 2.3). *Hopea cernua* and *Hopea pachycarpa* were especially abundant in the three selectively logged forest sites (Table 2.9). Other

species that were abundant in the logged forest sites were *Syzygium tawahense* (Myrtaceae), *Shorea parvifolia* (Dipterocarpaceae), *Gironniera nervosa* (Ulmaceae), *Palaquium calophyllum* (Sapotaceae) and *Neoscortechinia kingii* (Euphorbiaceae).

Species that were only abundant in the forest site 10 years ago were *Allanthospermum borneensis* (Simaroubaceae), *Canarium denticulatum* (Burseraceae), *Chaetocarpus castanocarpus* and *Macaranga gigantea* (both Euphorbiaceae), *Gluta renghas* (Anacardiaceae), *Madhuca malaccensis* (Sapotaceae), *Myristica villosa* (Myristicaceae), *Scaphium macropodum* (Sterculiaceae), *Shorea parvifolia, Shorea inappendiculata* and *Vatica nitens* (all Dipterocarpaceae). All these species were absent or rare in the forest sites logged 1 and 5 years ago.

No significant differences between forest sites were observed in other types of palm trees. Palm trees were only abundant in the forest sites logged 1 and 10 years ago. Most stems were *Oncosperma horridum* (Table 2.9). Even though this species has a multi-stemmed growth form, total stem densities of this species were rather low, particularly in the forest site logged 10 years ago. Stem clusters of this species were present in only seven plots of the forest site logged 1 year ago and five plots of the one forest site logged 10 years ago.

Monocot trees were only represented by species of *Oncosperma horridum*. This species occurred in very low densities in the four forest sites and was never observed in the forest site logged 5 years ago or in the primary forest site. In contrast to this, there were 7 stems presence among the 150 plots of the forest site logged 1 year ago, making it the dominant monocot tree of this forest type (Table 2.3).

Abundance and composition of different types of saplings

Dicot saplings had a similar abundance in all four forest sites, with stem densities of around 240 stems ha^{-1} (Tables 2.2, 2.4). In the primary forest site, the dominant families were Euphorbiaceae, Dipterocarpaceae, Myristicaceae, Ebenaceae, Sapotaceae, and Polygalaceae (Table 2.7).

Table 2.6
The ten most abundant families, genera and species of trees in the primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

	Trees – Primary forest	Abun	%	Selectively logged forest								
				1 year ago	Abun	%	5 years ago	Abun	%	10 years ago	Abun	%
Families												
1	Dipterocarpaceae (6, 22)	123	73.7	Dipterocarpaceae (6, 20)	98	61.6	Dipterocarpaceae (6, 25)	92	63.2	Dipterocarpaceae (6, 30)	138	86.7
2	Euphorbiaceae (10, 13)	51	21.8	Myrtaceae (1, 6)	29	29.2	Sapotaceae (2, 6)	69	37.3	Sapotaceae (3, 5)	72	29.2
3	Caesalpiniaceae (5, 5)	34	17.7	Lauraceae (6, 7)	41	28.7	Myrtaceae (1, 4)	45	28.8	Euphorbiaceae (7, 9)	49	25.0
4	Burseraceae (2, 5)	33	16.2	Euphorbiaceae 10, 15)	45	23.1	Euphorbiaceae (8, 13)	50	25.0	Simaroubaceae (2, 2)	48	23.2
5	Sapotaceae (2, 6)	32	15.2	Myristicaceae (4, 5)	43	21.0	Burseraceae (3, 6)	22	13.0	Myrtaceae (1, 4)	28	13.9
6	Verbenaceae (1, 2)	39	14.7	Ebenaceae (1, 5)	24	13.5	Lauraceae (3, 3)	21	12.1	Burseraceae (3, 4)	23	13.2
7	Flacourtiaceae (1, 1)	19	13.2	Caesalpiniaceae (5, 7)	14	10.8	Myristicaceae (4, 8)	25	11.8	Myristicaceae (4, 6)	23	12.0
8	Myrtaceae (2, 4)	23	12.3	Burseraceae (3, 6)	18	10.5	Sterculiaceae (3, 5)	11	10.7	Caesalpiniaceae (3, 3)	14	9.7
9	Ebenaceae (1, 5)	29	11.7	Sapotaceae (2, 7)	22	10.5	Caesalpiniaceae (3, 5)	14	10.4	Anacardiaceae (3, 3)	15	9.3
10	Guttiferae (3, 3)	19	8.6	Annonaceae (6, 8)	18	8.7	Anacardiaceae (3, 5)	13	8.3	Sterculiaceae (3, 4)	14	9.2
Genera												
1	Hopea (Dipt, 2)	78	44.5	Shorea (Dipt, 12)	70	45.3	Shorea (Dipt, 14)	38	33.6	Shorea (Dipt, 18)	78	51.4
2	Dipterocarpus (Dipt, 4)	15	14.9	Syzygium (Myrt, 6)	29	28.8	Syzygium (Myrt, 4)	45	28.4	Madhuca (Sapo, 2)	60	22.8
3	Teijsmanniodendron (Verb, 2)	39	14.4	Eusideroxylon (Laur, 1)	25	17.9	Madhuca (Sapo, 3)	56	26.2	Allanthospermum (Sima, 1)	47	21.8
4	Hydnocarpus (Flac, 1)	19	13.1	Diospyros (Eben, 5)	24	13.1	Hopea (Dipt, 2)	24	13.2	Dipterocarpus (Dipt, 7)	22	15.9
5	Shorea (Dipt, 12)	22	11.9	Palaquium (Sapo, 4)	19	8.7	Palaquium (Sapo, 3)	13	11.8	Syzygium (Myrt, 4)	28	13.5
6	Diospyros (Eben, 5)	29	11.4	Hopea (Dipt, 2)	11	8.0	Vatica (Dipt, 3)	19	10.3	Vatica (Dipt, 2)	19	9.5
7	Syzygium (Myrt, 3)	22	11.4	Myristica (Myri, 2)	14	7.8	Alseodaphne (Laur, 1)	14	8.4	Chaetocarpus (Euph, 1)	12	8.7
8	Canarium (Burs, 3)	20	10.3	Knema (Myri, 1)	16	7.6	Horsfieldia (Myri, 2)	15	7.2	Canarium (Burs, 2)	14	7.4
9	Chaetocarpus (Euph, 1)	19	9.6	Artocarpus (Mora, 2)	11	6.7	Barringtonia (Lecy, 2)	15	7.0	Gluta (Anac, 1)	11	7.1
10	Palaquium (Sapo, 2)	13	7.9	Gymnacranthera (Myri, 1)	12	6.4	Gluta (Anac, 3)	10	6.6	Scaphium (Ster, 1)	10	6.8

Table 2.6 (continued)

Species												
1	*Hopea semicuneata*	76	43.4	*Syzygium tawahense*	15	19.1	*Syzygium tawahense*	42	26.5	*Madhuca malaccensis*	58	21.6
2	*Hydnocarpus polypetala*	19	13.1	*Eusideroxylon zwageri*	25	17.7	*Madhuca malaccensis*	46	21.1	*Allanthospermum borneensis*	47	21.5
3	*Teijsmanniodendron coriaceum*	32	11.5	*Shorea parvifolia*	24	15.3	*Hopea cernua*	21	11.1	*Syzygium tawahense*	21	9.8
4	*Chaetocarpus castanocarpus*	19	9.6	*Shorea pinanga*	17	8.5	*Alseodaphne elmeri*	14	8.4	*Shorea parvifolia*	12	9.2
5	*Syzygium tawahense*	16	8.8	*Knema laurina*	16	7.5	*Palaquium stenophyllum*	7	6.6	*Shorea inappendiculata*	10	9.1
6	*Dipterocarpus lowii*	9	8.3	*Palaquium calophyllum*	16	7.2	*Horsfieldia polyspherula*	14	6.6	*Chaetocarpus castanocarpus*	12	8.6
7	*Cynometra elmeri*	16	7.7	*Syzygium caudatilimba*	8	6.4	*Neoscortechinia kingii*	11	6.4	*Vatica nitens*	13	7.1
8	*Palaquium stenophyllum*	12	7.2	*Gymnacranthera*	12	6.3	*Shorea pinanga*	6	6.3	*Gluta renghas*	11	7.0
9	*Diospyros curranii*	16	6.6	*farquhariana*			*Lithocarpus coopertus*	9	5.8	*Scaphium macropodum*	10	6.8
10	*Chionanthus sp.1*	15	5.9	*Hopea dryobalanoides*	9	6.1	*Drypetes kikir*	11	5.8	*Myristica villosa*	12	6.5
				Diospyros borneensis	11	6.1						

In columns after each taxon the corresponding abundance (Abun), expressed as the densities of stems exceeding (dbh ≥ 10 cm) in height 1.3 m, and the percentage of important value index of all stems of trees exceeding in 1.3 height (%). In parentheses after families the numbers of observed genera and species and after genera the corresponding family and the number of observed species.

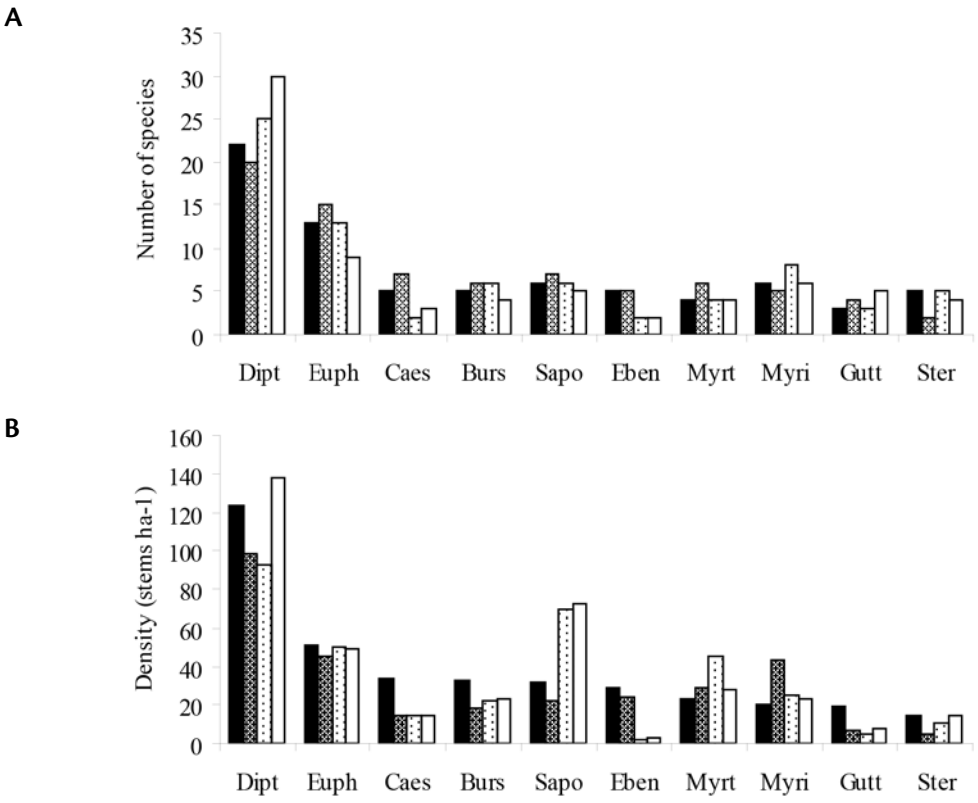

Figure 2.3
Stem density (A) and total observed species number (B) in four forest sites of the 10 most species-rich tree family of primary forest in Labanan, PT. Hutansanggam Labanan Lestari. Solid bars: primary forest site; cross-hatched bars: selectively logged forest; forest site logged 1 year ago; dotted bars: forest site logged 5 years ago; open bars: forest site logged 10 years ago.

Species that contributed greatly to the dominance of these families were *Hopea semicuneata* (Dipterocarpaceae), *Knema laurina* (Myristicaceae), *Croton argyratus, Koilodepas brevipes* and *Cleistanthus erycibifolius* (all Euphorbiaceae), *Xanthophyllum obscurum* (Polygalaceae), *Madhuca malaccensis* (Sapotaceae) and *Diospyros curanii* (Ebenaceae).

Generally the number of families of saplings in the 1 year ago logged site was about twice the number in the other sites (Table 2.7). However the differences between forest sites were less pronounced for the dominant dicot tree families (Table 2.6).

In the selectively logged forest sites, and particularly in the one logged 1 year ago, species of *Macaranga*, *Glochidion* and *Shorea* were more abundant than in the primary forest site. Apparently *Melastoma malabathricum* and *Glochidion arborescens* had ecological characteristics similar to species such as *Macaranga hypoleuca,* as it was fast-growing and particularly abundant in the selectively logged forest sites absent in the primary forest site (Table 2.7).

Dicot shrubs were the only life form more abundant in the forest site logged 5 years ago than in the other forest sites (Table 2.4). Dicot treelets were more abundance in the primary forest site than in the three logged ones. Typically, the dominant species were different in all four forest sites (Table 2.7). Some dicot liana species were abundant in the selectively logged forest sites, while being almost absent in the primary forest site. Species of *Uncaria* were only present in the forest sites 1 and 10 years ago (Table 2.9). Monocot herbs were less abundant than dicot herbs in the forest site logged 1 year ago and were absent in the three other forest sites (Table 2.4). Monocots were mainly represented by *Costus speciosus* (Table 2.9).

Abundance and composition of different types of seedlings

Dicot seedlings were more abundant in primary forest site than in the selectively logged forest sites, but total stem densities were highest in the forest site 10 years ago (Tables 2.2 and 2.5). In the primary forest site, the dominant families were Dipterocarpaceae, Euphorbiaceae, Annonaceae, Palmae and Ebenaceae (Table 2.8). The main representing these families were *Hopea semicuneata* and *Dipterocarpus acutangulus* (both Dipterocarpaceae), *Croton argyratus* and *Koilodepas brevipes* (both Euphorbiaceae), *Uvaria elmeri* (Annonaceae), *Daemonorops sabut* (Palmae) and *Diospyros macrophylla* (Ebenaceae).

There were significantly more small dicot liana seedlings in the forest sites logged 1 and 10 years ago, compared with the primary forest site (Table 2.5). Small dicot lianas were the only of species *Combretum nigricans* (Table 2.8) in the 2 × 2 m subplots. This species was very abundant in the forest site logged 1 year ago but was absent in the primary forest site. Seedlings of the species of *Strychnos axillaris* was present in the selectively logged forest sites, but were not observed in the primary forest site. Small dicot trees were more abundant in the primary forest site but not in the three logged ones (Table 2.5).

Dicot shrubs were more abundant in the forest site logged 1 year ago than in the other forest sites (Table 2.5). Dicot species were typically shrubs belonging to the genera of the Rubiaceae: *Ixora* and *Psychotria*. The first genus consists of

Table 2.7
The ten most abundant families, genera and species of saplings in the primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

	Saplings – Primary forest	Abun	%	Selectively logged forest								
				1 year ago	Abun	%	5 years ago	Abun	%	10 years ago	Abun	%
Families												
1	Euphorbiaceae (14, 16)	43	28.2	Euphorbiaceae (8, 13)	93	71.4	Dipterocarpaceae (5, 12)	38	42.7	Euphorbiaceae (7, 13)	35	40.8
2	Dipterocarpaceae (4, 9)	24	18.8	Dipterocarpaceae (2, 7)	24	23.7	Euphorbiaceae (9, 11)	43	41.2	Dipterocarpaceae (5, 13)	35	36.8
3	Myristicaceae (2, 3)	10	15.0	Myristicaceae (3, 4)	10	19.1	Sapotaceae (1, 3)	26	31.4	Melastomataceae (3, 5)	31	26.7
4	Ebenaceae (1, 4)	12	14.1	Myrtaceae (1, 4)	11	16.5	Burseraceae (2, 4)	13	18.7	Sapotaceae (2, 3)	15	22.7
5	Sapotaceae (2, 4)	11	14.0	Rubiaceae (5, 5)	17	15.3	Rubiaceae (4, 4)	15	17.7	Myrtaceae (1, 1)	11	19.0
6	Polygalaceae (1, 2)	9	13.5	Annonaceae (2, 4)	7	12.7	Lauraceae (4, 4)	12	15.1	Rubiaceae (7, 8)	18	16.3
7	Annonaceae (6, 6)	16	12.5	Ebenaceae (1, 3)	9	12.4	Myrtaceae (1, 2)	10	15.0	Ulmaceae (1, 1)	7	13.5
8	Myrtaceae (1, 4)	11	9.9	Tiliaceae (2, 2)	6	12.0	Annonaceae (4, 4)	9	10.9	Polygalaceae (1, 2)	8	13.1
9	Burseraceae (2, 3)	7	9.6	Sapotaceae (1, 2)	6	10.5	Polygalaceae (1, 3)	5	10.8	Anacardiaceae (3, 3)	10	10.7
10	Meliaceae (1, 3)	7	8.2	Papilionaceae (1, 1)	5	8.3	Fagaceae (2, 2)	4	10.6	Burseraceae (3, 5)	9	9.8
Genera												
1	Diospyros (Eben, 4)	12	15.3	Macaranga (Euph, 3)	37	24.9	Madhuca (Sapo, 3)	26	30.2	Shorea (Dipt, 7)	25	26.9
2	Xanthophyllum (Poly, 2)	9	13.7	Glochidion (Euph, 2)	32	23.0	Shorea (Dipt, 6)	21	23.4	Macaranga (Euph, 5)	12	19.4
3	Knema (Myri, 2)	8	11.7	Shorea (Dipt, 6)	23	20.8	Vatica (Dipt, 3)	12	17.0	Melastoma (Mela, 1)	27	19.2
4	Syzygium (Myrt, 4)	11	11.0	Syzygium (Myrt, 4)	11	15.4	Syzygium (Myrt, 2)	10	14.0	Syzygium (Myrt, 1)	11	18.0
5	Hopea (Dipt, 1)	10	10.2	Diospyros (Eben, 3)	9	11.4	Canarium (Burs, 2)	8	13.1	Madhuca (Sapo, 2)	12	18.0
6	Madhuca (Sapo, 2)	6	10.1	Knema (Myri, 2)	4	11.3	Koilodepas (Euph, 1)	15	12.4	Gironniera (Ulma, 1)	7	12.8
7	Croton (Euph, 2)	6	9.8	Koilodepas (Euph, 1)	10	10.1	Cleistanthus (Euph, 1)	10	11.9	Xanthophyllum (Poly, 2)	8	12.3
8	Cleistanthus (Euph, 2)	7	9.1	Palaquium (Sapo, 2)	6	9.7	Ixora (Rubi, 1)	11	10.2	Barringtonia (Lecy, 1)	3	9.3
9	Fordia (Papi, 1)	11	9.1	Baccaurea (Euph, 2)	4	9.2	Xanthophyllum (Poly, 3)	5	10.1	Fordia (Papi, 1)	7	7.6
10	Chionanthus (Olea, 2)	10	8.4	Polyalthia (Anno, 3)	5	8.9	Alseodaphne (Laur, 1)	6	8.3	Mallotus (Euph, 2)	6	7.6

Table 2.7 (continued)

Species												
1	*Hopea semicuneata*	10	10.2	*Glochidion arborescens*	25	16.8	*Madhuca malaccensis*	22	25.5	*Melastoma malabathricum*	27	19.1
2	*Fordia splendidissima*	11	9.0	*Macaranga hypoleuca*	24	16.0	*Syzygium tawahense*	9	12.4	*Syzygium tawahense*	11	17.8
3	*Knema laurina*	7	8.6	*Macaranga gigantea*	12	10.4	*Koilodepas brevipes*	15	12.2	*Madhuca malaccensis*	11	16.5
4	*Croton argyratus*	5	7.9	*Koilodepas brevipes*	10	10.0	*Cleistanthus erycibifolius*	10	11.7	*Gironniera nervosa*	7	12.6
5	*Xylopia ferruginea*	5	7.8	*Syzygium tawahense*	7	9.9	*Canarium denticulatum*	6	10.8	*Barringtonia macrostachya*	3	9.2
6	*Xanthophyllum obscurum*	3	7.1	*Knema laurina*	3	9.3	*Ixora fucosa*	11	10.1	*Xanthophyllum obscurum*	5	9.1
7	*Chionanthus sp.1*	8	7.0	*Fordia splendidissima*	5	7.5	*Vatica nitens*	4	8.4	*Shorea macroptera*	10	8.0
8	*Koilodepas brevipes*	7	7.0	*Diospyros borneensis*	6	7.2	*Alseodaphne elmeri*	6	8.2	*Fordia splendidissima*	7	7.5
9	*Xanthophyllum affine*	6	6.5	*Baccaurea sumatrana*	2	6.8	*Vatica oblongifolia*	7	7.3	*Macaranga hypoleuca*	5	7.3
10	*Cleistanthus erycibifolius*	4	6.4	*Chionanthus sp.1*	6	6.3	*Fordia splendidissima*	6	6.9	*Macaranga gigantea*	3	6.6

In columns after each taxon the corresponding abundance (Abun), expressed as the densities of stems exceeding dbh < 10 cm in height ≥ 1.5 m, and the percentage of important value index of all stems of saplings exceeding in dbh < 10 cm in height ≥ 1.5 m (%). In parentheses after families the numbers of observed genera and species and after genera the corresponding family and the number of observed species.

Table 2.8
The ten most abundant families, genera and species of seedlings in the primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

	Seedlings – Primary forest	Abun	%	Selectively logged forest								
				1 year ago	Abun	%	5 years ago	Abun	%	10 years ago	Abun	%
Families												
1	Dipterocarpaceae (4, 7)	92	37.7	Euphorbiaceae (8, 9)	42	21.9	Dipterocarpaceae (5, 11)	50	23.5	Dipterocarpaceae (5, 19)	65	30.2
2	Euphorbiaceae (7, 9)	47	24.7	Dipterocarpaceae (3, 5)	34	17.0	Euphorbiaceae (10, 11)	40	23.4	Melastomataceae (3, 3)	39	14.5
3	Annonaceae (4, 4)	20	11.3	Rubiaceae (8, 9)	22	15.3	Sapotaceae (2, 3)	29	15.8	Euphorbiaceae (11, 11)	17	12.2
4	Palmae (4, 4)	14	9.5	Melastomataceae (5, 5)	24	12.3	Papilionaceae (1, 1)	22	14.3	Papilionaceae (1, 1)	17	11.4
5	Ebenaceae (1, 4)	18	9.2	Lauraceae (6, 6)	12	9.1	Myrtaceae (1, 2)	22	13.5	Dryopteridaceae (1, 1)	25	9.7
6	Melastomataceae (2, 5)	11	8.5	Dryopteridaceae (1, 1)	13	8.7	Guttiferae (2, 2)	12	9.4	Sapotaceae (1, 1)	15	8.4
7	Oleaceae (1, 2)	11	7.8	Sapotaceae (3, 3)	16	8.2	Connaraceae (3, 3)	9	6.9	Guttiferae (3, 3)	11	8.1
8	Polygalaceae (1, 3)	8	6.1	Selaginellaceae (1, 1)	12	7.6	Melastomataceae (5, 6)	9	6.9	Rubiaceae (3, 3)	8	8.0
9	Rubiaceae (4, 4)	7	5.8	Myristicaceae (3, 3)	10	6.2	Burseraceae (2, 3)	8	6.5	Oleaceae (1, 1)	15	7.6
10	Symplocaceae (1, 1)	7	5.8	Anacardiaceae (5, 5)	7	6.0	Schizaeaceae (1, 1)	13	5.9	Anacardiaceae (3, 3)	12	6.7
Genera												
1	Hopea (Dipt, 1)	68	24.6	Shorea (Dipt, 3)	32	15.1	Fordia (Papi, 1)	22	13.3	Shorea (Dipt, 10)	38	19.3
2	Croton (Euph, 2)	22	11.9	Macaranga (Euph, 2)	20	9.8	Syzygium (Myrt, 2)	22	12.6	Melastoma (Mela, 1)	35	11.5
3	Diospyros (Eben, 4)	18	8.7	Nephrolepis (Dryo, 1)	13	8.2	Madhuca (Sapo, 2)	25	12.3	Fordia (Papi, 1)	17	10.4
4	Koilodepas (Euph, 1)	12	7.6	Selaginella (Sela, 1)	12	7.2	Koilodepas (Euph, 1)	17	10.3	Nephrolepis (Dryo, 1)	25	9.3
5	Chionanthus (Olea, 2)	11	7.2	Koilodepas (Euph, 1)	11	6.2	Calophyllum (Gutt, 1)	11	8.3	Madhuca (Sapo, 1)	15	7.8
6	Daemonorops (Palm, 1)	8	5.7	Combretum (Comb, 1)	11	4.9	Shorea (Dipt, 5)	13	7.0	Chionanthus (Olea, 1)	15	7.1
7	Pternandra (Mela, 3)	8	5.7	Diospyros (Eben, 2)	5	4.3	Vatica (Dipt, 2)	14	6.6	Dipterocarpus (Dipt, 4)	10	7.0
8	Xanthophyllum (Poly, 3)	8	5.7	Lygodium (Schi, 1)	9	4.3	Hopea (Dipt, 1)	16	6.0	Lygodium (Schi, 2)	15	5.7
9	Symplocos (Symp, 1)	7	5.4	Pternandra (Mela, 1)	8	3.9	Lygodium (Schi, 1)	13	5.6	Hopea (Dipt, 1)	9	5.4
10	Shorea (Dipt, 2)	11	5.3	Pleiocarpidia (Rubi, 1)	5	3.6	Dacryodes (Burs, 2)	7	5.0	Syzygium (Myrt, 2)	9	5.4

Table 2.8 (continued)

Species												
1	*Hopea semicuneata*	68	24.6	*Shorea parvifolia*	17	9.4	*Fordia splendidissima*	22	13.1	*Melastoma malabathricum*	35	11.4
2	*Croton argyratus*	21	11.6	*Macaranga hypoleuca*	17	8.8	*Madhuca malaccensis*	24	11.8	*Fordia splendidissima*	17	10.2
3	*Koilodepas brevipes*	12	7.5	*Nephrolepis bisserata*	13	8.1	*Syzygium tawahense*	20	11.8	*Nephrolepis bisserata*	25	9.2
4	*Chionanthus sp.1*	9	6.0	*Selaginella caulescens*	12	7.1	*Koilodepas brevipes*	17	10.2	*Madhuca malaccensis*	15	7.6
5	*Daemonorops sabut*	8	5.7	*Koilodepas brevipes*	11	6.2	*Calophyllum gracilipes*	11	8.2	*Chionanthus sp.1*	15	7.0
6	*Diospyros macrophylla*	14	5.6	*Combretum nigricans*	11	4.9	*Vatica nitens*	13	6.2	*Shorea macroptera*	12	5.4
7	*Symplocos crassipes*	7	5.4	*Shorea leprosula*	12	4.6	*Hopea cernua*	16	5.9	*Hopea cernua*	9	5.2
8	*Uvaria elmeri*	7	4.1	*Lygodium circinatum*	9	4.2	*Lygodium circinatum*	13	5.6	*Lygodium circinatum*	13	5.1
9	*Anaxagorea javanica*	4	3.8	*Pternandra rostrata*	8	3.9	*Gluta renghas*	7	4.9	*Syzygium tawahense*	7	4.7
10	*Dipterocarpus acutangulus*	8	3.7	*Bauhinia diptera*	7	3.6	*Alpinia galanga*	9	4.3	*Calophyllum gracilipes*	6	4.4

In columns after each taxon the corresponding abundance (Abun), expressed as the densities of stems exceeding per subplot 2 × 2 m, and the percentage of important value index of all stems of seedlings exceeding in subplot 2 × 2 m (%). In parentheses after families the numbers of observed genera and species and after genera the corresponding family and the number of observed species.

Table 2.9
Comparison between the number of trees (dbh ≥ 10 cm) per 1.5 ha, saplings (dbh < 10 cm) per 0.375 ha and several seedlings per 0.06 ha in ground cover recorded in subplot.

Family	Genus	Species	Life form	N0	N1	N2	N3	S0	S1	S2	S3
Trees (1.5 ha)											
▪ Dipterocarpaceae	Hopea	*cernua*	dicot tree	0	0	21	10	0	0	15	9
▪ Dipterocarpaceae	Hopea	*pachycarpa*	dicot tree	2	2	3	0	2	2	3	0
▪ Palmae	Oncosperma	*horidum*	palm tree	0	7	0	3	0	5	0	1
Saplings (0.375 ha)											
▪ Euphorbiaceae	Macaranga	*hypoleuca*	dicot tree	0	24	3	5	0	4	3	1
▪ Rubiaceae	Uncaria	*borneensis*	dicot liana	0	0	0	2	0	0	0	1
▪ Rubiaceae	Uncaria	*calophylla*	dicot liana	0	0	0	3	0	0	0	1
▪ Rubiaceae	Uncaria	*cordata*	dicot liana	0	6	0	0	0	1	0	0
▪ Zingiberaceae	Costus	*speciosus*	monocot herb	0	2	0	0	0	1	0	0
Seedlings (0.06 ha)											
▪ Cyperaceae	Mapania	*latifolia*	monocot grass	1	5	0	0	1	2	0	0
▪ Cyperaceae	Scleria	*terrestris*	monocot grass	2	3	0	0	1	2	0	0
▪ Dipterocarpaceae	Hopea	*semicuneata*	dicot tree	68	0	0	0	6	0	0	0
▪ Ebenaceae	Diospyros	*macrophylla*	dicot tree	14	0	0	0	2	0	0	0
▪ Euphorbiaceae	Macaranga	*hypoleuca*	dicot tree	0	17	1	1	0	5	1	1
▪ Ophioglossaceae	Helminthostachys	*zeylanica*	fern tree	0	3	0	0	0	3	0	0
▪ Selaginellaceae	Selaginella	*caulescens*	fern herb	0	12	0	0	0	5	0	0

After each family, genus and species name respectively life form, observed number of stems (N) and number of subplots having at least on stem exceeding of this species (S) per forest disturbance type (0 = primary forest site, 1 = forest site logged 1 year ago, 2 = forest site logged 5 years ago, 3 = forest site logged 10 years ago).

species that were mainly restricted to the primary forest site, while *Psychotria* sp.1 was most abundant in the forest site logged 1 year ago.

Monocot herbs were abundant in the forest site logged 5 years ago (Table 2.5) and this was mainly due to extensive ground cover of *Alpinia galanga* (Table 2.8), which was absent or rare in the other three forests.

Grass-like monocots were more abundant in the forest site logged 1 year ago (Table 2.5), mainly due to plentiful ground cover of *Mapania latifolia* and *Scleria terrestris* (Table 2.9). Both species were absent in two other logged forest sites.

Both palm lianas (rattans) and small palm trees were more abundant in the primary forest site than in the three selectively logged forest sites (Table 2.5). The climbing palm *Daemonorops sabut,* was the only climber that was very abundant in the primary forest site (Table 2.8). Other species were rare in all four forest sites.

Small liana ferns were more abundant in the forest site logged 5 year ago than in the other forest sites (Table 2.5). Two genus *Lygodium* and *Stenochlaena,* were abundant in the forest site logged 5 years ago, while in the other three forest sites these genera were absent or rare. These genera often form a very tangled mat at places where the small pioneer trees and small lianas are absent or rare.

Both herbaceous and small tree ferns were abundant in selectively logged forest sites, but were absent in the primary forest site (Table 2.5). Small tree ferns were represented solely by *Helmintostachys zeylanica,* a species that was only observed in the forest site logged 1 year ago. Of the same life form, the species *Selaginella caulescens* was also very abundant in the forest site logged 1 year ago, but absent in the three other forest sites (Table 2.9).

Discussion

Changes in forest structure and composition after logging compared to primary forest

Biodiversity levels indicate the stability of a forest community: the higher the levels of biodiversity, the more stable the community (Richards, 1964; Whitmore, 1990). In our study we compared forest sites which were logged 1, 5 and 10 years ago and a primary forest site. Our study covered canopy and forest floor vegetation, trees, saplings and seedlings, climbing trees (liana and rattan), non-rattan palms, herbs, epiphytes, and mosses.

Since we included 10 years ago logged forests, a before-, between- and after treatment study was not possible. We also did not include a heavily logged forest site, because these were not available within the forest concession. The distance of 50 m between the five transects per site is limited (risk of pseudo replication), but this distance has been used in other studies and is proposed as a standard by several authors (Slik *et al.*, 2002). The present comparison of the four forest sites: three forest sites logged selectively 1, 5 and 10 years ago (certified logging) and a primary forest site provides important information on the status of logged lowland rain forest in East Kalimantan. The logging procedures of our study sites are described in detail (Meijaard *et al.*, 2005). The present study showed that overall tree densities were significantly higher in the forest site of primary forest than in the sites 1 and 5 years ago, but approximately similar to that in the forest site logged 10 years ago (Table 2.3). The number of tall trees (dbh ≥ 10 cm) is very similar in the three logged forest sites of Labanan (492–558 stems ha^{-1}), suggesting that the impact of selective logging was similar for the three sites (Table 2.2). Nevertheless, we found small though significant differences in stem densities in the forest sites logged 1 and 5 years ago compared with the primary forest site (Table 2.3). In addition, typical sapling and seedling life forms, such as the fast growing species *Macaranga hypoleuca* were very abundant in the forest site logged 1 year ago less abundant in the forest sites 5 and 10 years ago, and absent in the primary forest site (Table 2.9). *Macaranga hypoleuca* is a very common and characteristic pioneer tree species in most of Southeast Asia and especially in East Kalimantan (Primack & Lee, 1991; Davies *et al.*, 1998; Slik *et al.*, 2000, 2002; Eichhorn *et al.*, 2006). Without information on species composition and diversity, a comparison of the vegetation structure in the four forests sites therefore suggested that selective low impact logging largely compensated for the strong negative impact of initial logging. However, we found that only a small number of pioneer tree species accounted for the high small tree densities in the forest site 10 years ago (Table 2.5). Our result therefore show that abundance of tree species regeneration, as was observed at several sites in East Kalimantan (e.g. Siegert *et al.*, 2001; Slik *et al.*, 2002; Yassir *et al.*, 2010), does not in itself, ensure recovery of the forest's original botanic diversity. Information on species composition is needed to know how many species of trees and other plants are able to recover in the selectively logged forest sites (Tables 2.3, 2.4 and 2.5).

The total number of saplings species belonged to one or a few different species in the selectively logged forest sites (Tables 2.4); this means that new trees of sapling which entered the overstorey (dbh ≥ 10 cm), whereas the in-growth of seedlings in the selectively logged forests consisted of many species (Table 2.5); this was apparently due to more light on the open places to grow the pioneer species (Arbainsyah, pers. obs.). This finding doesn't contradict the generally held view

that pioneer species occur only after disturbance when the light or temperature levels are raised substantially (Bazzaz & Pickett, 1980; Uhl & Clark, 1983; Swain & Whitmore, 1988; Vazques-Yanes & Orozco-Segovia, 1993; Eichhorn *et al.*, 2006). After selective logging of the forest, many small pioneer tree seedlings were therefore likely to be available for tree establishment and this would explain why in a forest site, which was logged previously, seedlings could become dominant. This explanation implies that after selectively logging, there will not be a permanent deforestation at Labanan, as ingrowth of seedlings of small trees in the topsoil were most abundant in the forest site logged 10 years previously (Figure 2.2).

10 years after selective logging, the sapling and tree densities were still high in the forest sites, but rather low in the forest sites logged 1 and 5 years ago, compared with the primary forest site. Apart from the differences in tree densities, there was also a difference in tree composition among the selectively logged forest sites (1, 5 and 10 years ago). The most abundant tree species in the forest site logged 10 years ago were *Madhuca malaccensis*, *Allanthospermum borneensis* and *Syzygium tawahense* (Table 2.6). *Syzygium tawahense* also belongs to the highest 10 most abundant tree species of forest sites logged 1 and 5 years ago (Table 2.6, Figure 2.4).

The impact of selective logging on plant diversity

Comparison of the plant diversity in different habitats shows that the overall impact of logging on plant species richness is highly dependent on the scale of assessment. We realize that the maximum number of 156 tree species we found in our study does represent of the tree species diversity in Borneo (Raes, 2009). Since most species in hyperdiverse rainforests occur in low densities, their response to logging can not be assessed with small sampling plots only. So we suggest that our study at best, gives an indication of an impact of logging on the more common tree species. We also realize that the tree category > 10 cm dbh will include a wide range of diameter classes, which may have changed following logging. Therefore we recommend including more diverse diameter categories in a follow-up study (Tables 2.3, 2.4 and 2.5). Logging in a sense is equivalent to gap formation in the forest canopy, but at a much larger scale and will surely alter the nature of the original forest (Kartarwinata, 1977; Eichhorn *et al.*, 2006). Similar scale-dependent effects of disturbance on species diversity have also been reported by other studies, for example on the abundance of bark beetles in pine forests of Finland (Poltonen et al. 1998). In tropical rain forests, the impact of logging on species richness and evenness in butterflies has been shown to be highly scale-dependent as well (Hamer & Hill, 2000; Cleary, 2002; Summerville & Crist, 2002). As a result, numbers of trees and small dicot trees were always higher in the primary forest site (Tables 2.3, 2.6), this was mainly due to the

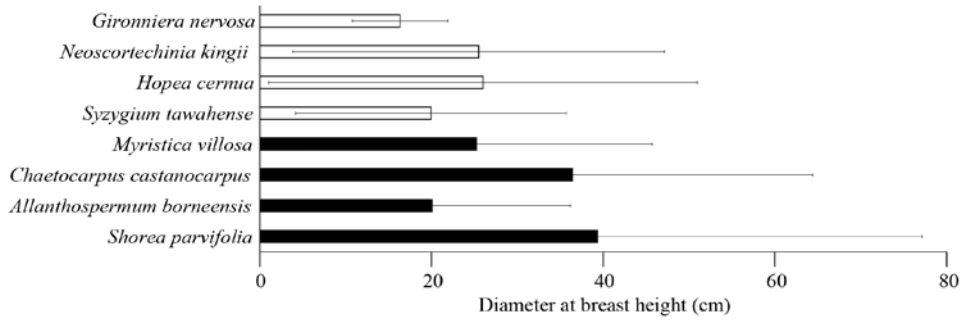

Figure 2.4
Diameter at breast height (average + standard deviation) of four species abundant in three logged forest sites (open bars) and of four species abundant only in forest site logged 10 years ago (solid bars).

abundant regeneration of invasive species such as *Hopea semicuneata* (Tables 2.7, 2.8), this species is not logged and the mother tree was absent in the three logged forest sites (Table 2.9). For forest regeneration it is important that the high richness of saplings were found in the forest site logged 1 year ago (Table 2.4). When taxonomic composition was compared species diversity was higher in the in the forest site logged 1 year ago than in the primary forest site (Table 2.3). Our study showed that the abundance of Caesalpiniaceae was considerably decreased in the selectively logged forest sites relative to the primary forest site, whereas the abundance of Dipterocarpaceae, Sapotaceae and Euphorbiaceae increased in the selectively logged forest sites (Figure 2.3). The latter family is typical fast-growing pioneer taxa throughout the tropics (Turner, 2001) and are of little economic interest. Our results show that, despite attaining a height comparable to that of the primary forest site, selectively logged forest sites have different plant taxa (Tables 2.3, 2.4 and 2.5).

Total numbers of trees accounted for a higher overall plant diversity in primary forest sites, while the number of tree species was higher in the forest site logged 1 year ago (Table 2.3). Saplings had a more or less similar diversity in all forest sites, while the number of sapling species was higher in the primary forest site (Table 2.4). While numbers of in-growth of seedlings was higher in the forest site logged 10 years ago, the number of seedling species was higher in the forest site logged 1 year ago (Table 2.5).

Conclusions

Overall, our study has revealed a rich natural vegetation on Borneo and major differences in the vegetation structure, composition and in plant diversity be-

tween selectively logged forest sites and a primary forest site. We have confirmed the importance of distinguishing between primary forests as opposed to selectively logged forests for documenting and interpreting plant species richness for sustainable forest exploitation in tropical rain forest. Selectively logged rain forest of this study still showed a high regenerating diversity of plants.

Logging practices in selectively logged forest with normal management operations have not resulted in a high deforestation of the study sites. The tree numbers still recovered with abundant regeneration. The numbers of tree species composition were clearly affected and neither increased nor decreased within forest sites logged 5–10 years ago.

Composition of saplings species were fewer within in selectively logged forest sites, in the 5–10 years ago-logged sites than in primary forest site. This indicates that the selectively logged forests have more or less the same value in evenness number species. These saplings will therefore slowly form a lower and lower proportion of all saplings present in selectively logged forest sites. That means that the impact of logging results in the same proportion of the total number of saplings in all selectively logged forest sites in near future.

The ingrowth of seedlings of the *Macaranga hypoleuca* was found to be independent of the light availability in the forest understorey. Instead the number of this species depended strongly on the presence of mature parent trees species in and around the forest sites. This caused one species (*Macaranga hypoleuca*) to be the most dominant species in the 1 year ago logged forest site. In the 5 and 10 year ago forest sites Macaranga hypoleuca seedlings were probably replaced by competition with seedlings from other species. However, apart from seedling numbers, did depend strongly on the light availability in the forest understorey.

The diversity index used as indicators the stability regeneration for all growth stage of forest community showed that were still floristically very diverse and indicated that the selectively logged forest sites affected the abundance of species rather than species richness itself. This renders the selectively logged forest still valuable for conservation, especially since the studied forests were in selectively logged forest sites and tree species diversity to be higher in diversity of plant.

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