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

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Plant communities in FSC-candidate, selectively logged forests compared to primary forest in relation to stem diameter and plant functional types

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Abstract

The aim of our study is to analyze the impact of selective logging and forest recovery on patterns in forest structure, tree species composition, and tree species diversity in relation to stem diameter and Plant Functional Type (PFT). Our study compared FSC-candidate forest sites which had been logged selectively 1, 5 and 10 years ago to primary lowland dipterocarp rainforest in the Berau region of East Kalimantan. Logged forest sites under different logging regimes showed significant differences in forest structure compared with the primary forest site. In the diameter class, some logged forest sites showed a significant reduction in the frequency of diameter classes compared to the primary forest site. The diameter classes were significantly smaller and the number of tree species was significantly lower in the selectively logged forest sites compared to the primary forest site. Species specific wood density was used to assign species to three classes of PFT (light, medium, heavy wood). Logging increased the number of light hardwood stems in small diameter classes. In the larger diameter classes (> 60 cm dbh) a strong increase of light hardwood numbers were found in the selectively logged forest sites. Our results indicate that both diameter classes and plant functional types are affected by selective logging and recovery after logging in tropical lowland forest.

Key words: Forest recovery; Growth form; Kalimantan; Species richness; Tropical rain forest.

Introduction

Most of the tropical rainforest lowland areas in East Kalimantan were covered with primary dipterocarp forest until the early 1970s (Slik *et al.*, 2002). At present however, most of these lowland dipterocarp forests have been selectively logged, burnt, or converted into agricultural land (oil palm), with only a few small undisturbed areas remaining (Slik *et al.*, 2002; Slik & Eichhorn, 2003; Eichhorn *et al.*, 2006; Arbainsyah *et al.*, 2014). Recovery of the vegetation to pre-logging conditions will be slow since logging in tropical forest has a significant effect on the forest understorey (Webb, 1998; Woods, 1998; Pinard *et al.*, 2000; Slik *et al.*, 2002). Two certification systems for sustainable forest management have been introduced in Indonesia: the international Forest Stewardship Council (FSC) and the national Lembaga Ekolabel Indonesia (LEI). The Lembaga Ekolabel Indonesian selective logging system allows a selective logging intensity of ≤ 8 trees/ha and tree cutoffs in the diameter > 60 cm associated with a felling cycle of 40–60 years depending on site conditions (Sist *et al.* 2003; van Kuijk *et al.* 2009). Although FSC is an internationally recognized certification system claiming to guarantee sustainable timber offtake from tropical rainforests (ITTO, 2004), the impact of FSC-certified logging on biodiversity has rarely been quantified (Van Kuijk *et al.*, 2009).

Studies in which the impact of tropical deforestation by commercial logging on tree diversity and forest structure has been addressed (Slik *et al.*, 2002; Verburg & Van Eijk-Bos, 2003; Arbainsyah *et al.*, 2014) provided limited information on the impact of certified selective logging and forest recovery. Through the present research we will specifically target the lack of knowledge about suitable biological indicators for sustainable forest management at the forest management unit level (Ghazoul & Hellier, 2000; De Jongh & Persoon, 2010).

Important factors for forest recovery are: 1) seed bank, 2) topography and 3) light (Woods, 1998; Fredericksen & Mostacedo, 2000; Slik & Eichhorn, 2003; Arbainsyah *et al.*, 2014). The majority of plants in lowland forest of Kalimantan are non-pioneer species, which are lacking soil seed banks, while seed import from surrounding primary forest areas is likely to be low since these have been heavily impacted by logging activities (Garwood, 1989; Verburg & Van Eijk-Bos 2003; Eichhorn *et al.*, 2006). Increased light levels in the understorey of logged forests result in the rapid growth of many herbaceous and woody pioneer species. Since climax species usually have no seed bank (Swaine & Whitmore, 1988; Garwood, 1989; Vazquez-Yanes & Orozco-Segovia, 1993; Eichhorn *et al.*, 2006), the early recovery of these species in logged forests strongly depends on surviving saplings, sprouting trees and germination of seeds from the seed rain (Slik *et*

al., 2002; Slik & Eichhorn, 2003). This would have important consequences for tropical forest recovery after logging and should therefore be considered in the development of any sustainable forest management system.

The most important factor influencing forest recovery after logging is the increased light penetration to the forest floor. Canopy openness at ground level (1–2 m height) generally increases from 2–7% in old growth forest to 20–30% in selectively logged forest (Slik *et al.*, 2002). Increased light intensities combined with the reduced number of plants in the forest understorey favor the establishment of pioneers (Nieuwstadt *et al.*, 2001; Slik *et al.*, 2002; Slik & Eichhorn, 2003; Eichhorn *et al.*, 2006; Arbainsyah *et al.*, 2014). These pioneers will compete with surviving trees for available resources, especially light. Since pioneer species can have very high growth rates under high light conditions (e.g. after logging), regeneration of other tree species in the forest landscape might be seriously hampered (Uhl *et al.*, 1981; Slik *et al.*, 2002; Slik & Eichhorn, 2003; Arbainsyah *et al.*, 2014).

Both the tree species diversity and the forest structure, in terms of species per diameter class are considered to be important factors to take into account when measuring the impact of SFM (Ter Steege & Hammond, 1996, 2001; Verburg & Van Eijk-Bos, 2003; Meijaard *et al.*, 2005). Logging activities affect ecosystem processes in many different ways, but could be especially harmful to endemic populations of plants and animals (Verburg & Van Eijk-Bos, 2003; Sist *et al.*, 2003; Meijaard *et al.* 2005; Arbainsyah *et al.* 2014). In the process of succession after logging, pioneer trees reach successively larger diameter classes faster than most non-pioneer species (Slik *et al.*, 2002; Verburg & Van Eijk-Bos 2003). In addition, some light demanding, non-pioneer tree species may have higher growth rates after logging (Slik *et al.*, 2002; Slik & Eichhorn, 2003). Differential species response to disturbance after logging can result in differences in tree composition within tree diameter classes (Sheil, 1999; Okuda *et al.*, 2003; Verburg & Van Eijk-Bos, 2003). A classification derived from the pioneer versus climax species concept was published by Swaine and Whitmore (1988) and is often used to analyze the impact of pioneer species on forest recovery (e.g. Slik & Eichhorn, 2003). One study of primary forest succession used an analysis in which the data set was divided into different stem diameter classes to unravel changes in the tree community compared to primary forest succession in Uganda (Sheil, 1999). Recently, species-specific Plant Functional Types (PFT) have been used by several authors (Brown & Lugo 1990; Ter Steege & Hammond, 1996, 2001; Verburg & Van Eijk-Bos, 2003). With the PFT, a trade-off is assumed between growth rate of the PFT classes light, medium and heavy hardwood. Species that produce light hardwood can grow quickly and are able to emerge rapidly after gap for-

mation. At the other extreme, species that produce heavy hardwood have lower growth rates (Verburg & Van Eijk-Bos, 2003).

Here we present a detailed analysis of the tree communities, and the abundance of different PFTs in primary forest and forest selectively logged 1, 5 and 10 years ago in East Kalimantan. Patterns in species diversity and composition are related to diameter classes and Plant Functional Types and analysed for selectively logged forest sites and to compare these with primary forest.

Materials and methods

Study area

The study area is located in lowland forest within the Perseroan Terbatas-PT. Hutansanggam Labanan Lestari forest concession in Labanan, Berau district, in the northeastern part of the Indonesian province of East Kalimantan (Figure 3.1). The largest part of this concession area belongs to the state-owned logging company Perseroan Terbatas-PT. Inhutani I. The elevation range within the study area is 25 to 140 m above sea level. The topography within the study area in all sites consists of a relatively homogenous rolling hilly landscape with shallow valleys and gullies. The forest type can be described as a Dipterocarp hill forest which is relatively homogenous throughout all study sites. The soils consist of loamy clay and sandy soils with a top soil layer of approximately 5-10 cm (Mantel *et al.*, 2002).

Forest structure

Sites were selected in primary forest (1 site) and selectively logged forest (3 sites) (Figure 3.1). In each site, all trees were systematically recorded along a line transect of 10 × 300 m. In total, 20 line transects were sampled: 5 in primary forest and 5 in each of the 3 selectively logged forest areas. We divided each line transect into 30 plots of 10 × 10 m (a total of 150 plots in each site). The Basal Area (BA) removed by logging and total damage caused by logging on the number of stems was derived from field measurements of trees with a dbh ≥ 10 cm. Basal Area (BA) was calculated as $BA = \pi \times (0.01 \times dbh / 2)^2$ (Jost 2006). Plants were sampled and later identified at the Wanariset Herbarium Samboja, i.e. in case of a fertile plant, and labeled (vouchers stored in the Herbarium Wanariset Samboja, Indonesia). Tree species diversity and tree density in the plots were compared across diameter classes and disturbance types (primary, logged selectively 1, 5 and 10 years ago) (Figure 3.1).

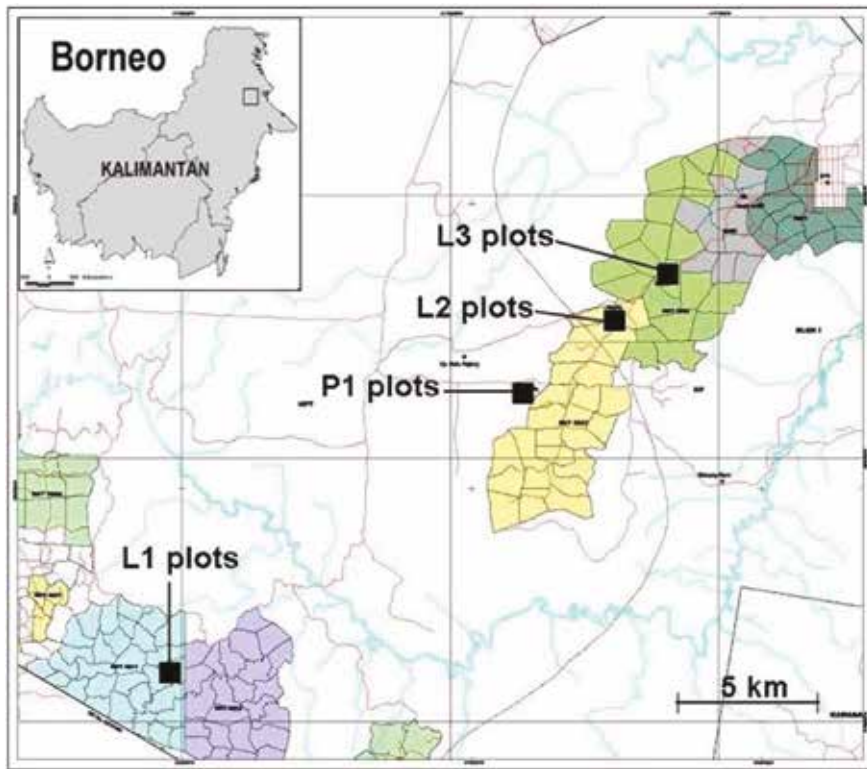


Figure 3.1

Map of East Kalimantan with the location of study sites: 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).

Tree species composition

Trees classified by Plant Functional Types (PFT) and the tree diameter composition of the forest were used to summarize compositional dynamics based on taxonomic literature (Burgess, 1966; Soerianegara & Lemmens, 1993; Lemmens *et al.*, 1995; Sosef *et al.*, 1998; Slik & Eichhorn 2003; Verburg & Van Eijk-Bos 2003) and information from herbarium labels of specimens stored in the Wanariset Herbarium Samboja. All tree stems were grouped into the following diameter (dbh) classes: 10–<20 cm (small trees), >20–30 cm (lower and middle canopy trees), >30–40 cm, >40–50 cm, >50–60 cm (middle and upper canopy trees), >60–70 cm, >70–80 cm, >80 cm (emergent trees). The number of tree species and number of individual trees in each diameter class in the primary forest site and the selectively logged forest (3 sites) is shown in Figure 3.1.

Plant functional types in tree densities

To study the growth rate relationship between PFT, in each site the average tree species diameter was calculated for all stems and species. For PFT classifications, wood descriptions for tree species were derived from Burgess (1966); Soerianegara and Lemmens (1993); Lemmens *et al.* (1995); Sosef *et al.* (1998) and Verburg and Van Eijk-Bos (2003). Relations between PFT and tree density were determined by summing the number of trees in the three PFT classes (light, medium and heavy hardwood) within each disturbance type (primary forest, forest logged selectively 1, 5 and 10 years ago).

Data analyses and statistics

Statistical analyses were performed using Microsoft Excel and SPSS 13.0 software. We calculated the mean and standard deviation for the tree densities per diameter class, and tree species number per diameter class by the three PFT classes (light, medium and heavy hardwood). Data were log transformed to normalize the distribution. Tree species diversity within plots was compared between the selectively logged forest and primary forest sites. These comparisons were made to compensate for differences in sample sites between selectively logged forest sites in comparison to a primary forest site. Differences between sites were tested using the Fisher's Least Significant test (one-way ANOVA, using log transformed data, with Bonferroni multiple comparison test).

Results

Forest structure after selective logging

Compared to the primary forest site, Basal Area (BA) was significantly lower in forest sites logged selectively 1 and 5 years ago, but not significantly different in the forest site logged 10 years ago (Table 3.1). Throughout the selectively logged forest sites, no significant differences were found in the number of tree stems removed, the total number of damaged tree stems, the BA of tree stems removed or total damage to the number of tree stems (Table 3.1).

We compared the abundance of stems per size class for forest selectively logged 1, 5 and 10 years ago. Throughout the sites, the number of stems in the smallest diameter class (10–20 cm dbh per 100 m²) appeared to be higher than the number of stems in the other diameter classes (>20 cm dbh) (Table 3.2). The forest site logged selectively 1 year ago had a significantly lower number of stems in the

>20–30 cm dbh class than the primary forest site. The forest sites logged selectively 5 and 10 years ago had significantly lower numbers of stems in the 10–<20 cm dbh class than the primary forest site (Figure 3.2a; Table 3.2).

Table 3.1

Forest type (primary forest, selectively logged forest: 10, 5 and 1 year ago), average basal area (BA) before logging (BA = estimated for logged forest sites), number of stems, BA removed by logging and total damage to all stems ≥ 10 diameter caused by logging on the number of stems and BA. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests).

Forest type	Present BA* (per 100 m ²)	Removed (per 100 m ²)		Total damage (per 100 m ²)	
		Stems	BA	Stems	BA
Primary forest	0.31 $\pm$ 0.35	0	0	0	0
Logged, 10 year ago	0.23 $\pm$ 0.20	0.09 $\pm$ 0.29	0.04 $\pm$ 0.13	0.43 $\pm$ 0.73	0.06 $\pm$ 0.13
Logged, 5 years ago	0.20 $\pm$ 0.19	0.10 $\pm$ 0.32	0.04 $\pm$ 0.15	0.35 $\pm$ 0.58	0.07 $\pm$ 0.17
Logged, 1 years ago	0.20 $\pm$ 0.28	0.07 $\pm$ 0.26	0.03 $\pm$ 0.13	0.33 $\pm$ 0.56	0.06 $\pm$ 0.15

There were no significant differences in the number of stems in the 30–70 cm dbh class between the forest sites selectively logged and the primary forest site. However, the number of stems in the >70–80 cm dbh class was significantly lower in the forest sites logged selectively 1 and 5 years ago than in the primary forest site (Table 3.2). No significant differences were found in the number of stems in the > 80 cm dbh class across all forest sites (Table 3.2).

The number of tree species in the >20–30 cm dbh class per surface area was significantly lower in the forest selectively logged 1 year ago than in the primary forest site (Table 3.3). The number of tree species in the >30–70 cm dbh class did not differ significantly between any selectively logged site and the primary forest site. The number of tree species in the >70–80 cm dbh class was significantly lower in the forest sites selectively logged 1 and 5 years ago than in the primary forest site (Table 3.3). No significant differences were found in the number of tree species > 80 cm dbh throughout the forest sites (Table 3.3).

Tree species composition according to diameter class

The number of tree species in the 10–<20 cm dbh class in the selectively logged forest sites 5 and 10 years ago was significant lower than in the primary forest site (Table 3.3). However, the total number of tree species in the 10–<20 cm dbh class was higher in the forest site selectively logged 1 year ago than in all other forest sites (Figure 3.2b). In some selectively logged forest sites, the number of tree species

Table 3.2

Comparison between the abundance number of tree individuals per dbh class (average $\pm$ standard deviation) for all species combined and forest sites.

Forest type	Abundance stems (per 100 m ²)							
	10 - < 20 cm	> 20 - 30 cm	> 30 - 40 cm	> 40 - 50 cm	> 50 - 60 cm	> 60 - 70 cm	> 70 - 80 cm	> 80 cm
Primary forest	2.34 $\pm$ 1.66	0.85 $\pm$ 0.86	0.37 $\pm$ 0.63	0.26 $\pm$ 0.50	0.09 $\pm$ 0.31	0.05 $\pm$ 0.23	0.08 $\pm$ 0.27	0.03 $\pm$ 0.20
Logged, 10 years ago	1.85 $\pm$ 1.21	0.97 $\pm$ 0.95	0.41 $\pm$ 0.59	0.24 $\pm$ 0.49	0.13 $\pm$ 0.37	0.08 $\pm$ 0.27	0.03 $\pm$ 0.18	0.01 $\pm$ 0.08
Logged, 5 years ago	1.79 $\pm$ 1.46	0.82 $\pm$ 1.00	0.27 $\pm$ 0.52	0.23 $\pm$ 0.47	0.14 $\pm$ 0.38	0.06 $\pm$ 0.24	0.02 $\pm$ 0.14	0.01 $\pm$ 0.08
Logged, 1 years ago	1.99 $\pm$ 1.58	0.55 $\pm$ 0.75	0.39 $\pm$ 0.67	0.20 $\pm$ 0.49	0.07 $\pm$ 0.26	0.04 $\pm$ 0.20	0.01 $\pm$ 0.08	0.03 $\pm$ 0.18

Abundance expressed as densities of stems exceeding 1.3 m in height. The number of species in dbh classes $\geq$ 10 cm on 1.5 ha (150 times 10x10 m) in the primary forest site and three selectively logged forest sites: logged 10, 5 and 1 year ago. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests)

Table 3.3

Comparison between the abundance of tree species per dbh class (average $\pm$ standard deviation) for all trees combined and forest sites.

Forest type	Species (per 100 m ²)							
	10 - < 20 cm	> 20 - 30 cm	> 30 - 40 cm	> 40 - 50 cm	> 50 - 60 cm	> 60 - 70 cm	> 70 - 80 cm	> 80 cm
Primary forest	2.18 $\pm$ 1.55	0.82 $\pm$ 0.82	0.35 $\pm$ 0.58	0.26 $\pm$ 0.50	0.09 $\pm$ 0.31	0.05 $\pm$ 0.23	0.08 $\pm$ 0.27	0.03 $\pm$ 0.20
Logged, 10 year ago	1.74 $\pm$ 1.10	0.95 $\pm$ 0.94	0.41 $\pm$ 0.59	0.24 $\pm$ 0.49	0.12 $\pm$ 0.35	0.08 $\pm$ 0.27	0.03 $\pm$ 0.18	0.04 $\pm$ 0.20
Logged, 5 years ago	1.72 $\pm$ 1.40	0.79 $\pm$ 0.96	0.27 $\pm$ 0.50	0.23 $\pm$ 0.47	0.14 $\pm$ 0.38	0.06 $\pm$ 0.24	0.02 $\pm$ 0.14	0.03 $\pm$ 0.16
Logged, 1 years ago	1.86 $\pm$ 1.47	0.53 $\pm$ 0.72	0.38 $\pm$ 0.66	0.19 $\pm$ 0.46	0.07 $\pm$ 0.26	0.04 $\pm$ 0.20	0.01 $\pm$ 0.08	0.01 $\pm$ 0.12

Abundance expressed as densities of stems exceeding 1.3 m in height. The number of species in dbh classes $\geq$ 10 cm on 1.5 ha (150 times 10x10 m) in the primary forest site and three selectively logged forest sites: logged 10, 5, and 1 year ago. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests)

increased with increasing diameter classes up to the >60 cm dbh class, whereas for the >60 cm dbh classes, the number of species decreased with decreased diameter classes in selectively logged versus the primary forest site (Figure 3.2b).

Table 3.4 summarizes the relative abundance of tree species in the primary forest site and selectively logged forest sites in each PFT class. The classes of PFT in heavy hardwood and the total number of species were comparable in abundance in all four forest sites, with a total species abundance of around 22 species ha⁻¹ (Table 3.5). In the primary forest site, the dominant PFT species in heavy hardwood were *Cynometra elmeri* (Caesalpiniaceae), *Hopea semicuneata* (Dipterocarpaceae) and *Teijsmanniodendron coriaceum* (Verbenaceae).

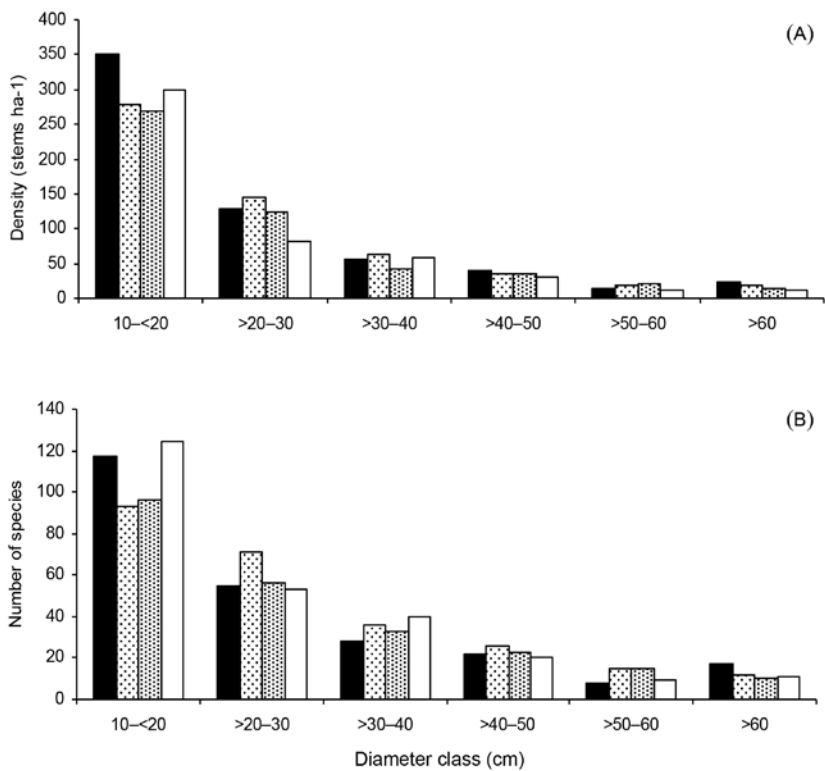


Figure 3.2

Stem density (A) and total observed species number (B) in four forest sites of the relative distribution among trees ≥ 10 cm dbh classes of primary forest in Labanan, PT. Hutansanggam Labanan Lestari. Solid bars: primary forest site; cross-hatched bars: selectively logged forest site logged 10 years ago; dotted bars: forest site logged 5 years ago; open bars: forest site logged 1 year ago.

The greatest abundance in total number of tree species was found for the medium hardwood PFT class, with 73 species in the forest site selectively logged 1 year ago and 72 in the primary forest site; the overall number of species for the medium hardwood PFT class was much lower in the other forest sites (Table 3.5). The light hardwood PFT class had a higher total number of tree species in the forest site logged 1 year ago than all other forest sites (Table 3.5). As expected, pioneer species, notably *Macaranga gigantea* (Euphorbiaceae), had a high abundance of tree species in the forest site selectively logged 10 years ago; none were observed in the other forest sites (Table 3.4).

Table 3.4

List of plant functional types of light, medium and heavy hardwood (Burgess 1966; Soerianegara & Lemmens 1993; Lemmens et al. 1995; Sosef et al. 1998) of tree species that are abundant in at least one of the forest sites.

Plant functional types	Species name	Primary forest	Selectively logged forest		
			10 yrs ago	5 yrs ago	1 yr ago
Light	<i>Alseodaphne elmeri</i> (Lauraceae)	–	–	+	–
	<i>Barringtonia macrostachya</i> (Lecythidaceae)	–	–	+	–
	<i>Gymnacranthera farquhariana</i> (Myristicaceae)	–	–	–	+
	<i>Horsfieldia polyspherula</i> (Myristicaceae)	–	–	+	–
	<i>Knema laurina</i> (Myristicaceae)	–	–	–	+
	<i>Macaranga gigantea</i> (Euphorbiaceae)	–	+	–	–
	<i>Myristica villosa</i> (Myristicaceae)	–	+	–	–
	<i>Neoscortechinia kingii</i> (Euphorbiaceae)	–	+	+	–
Medium	<i>Shorea parvifolia</i> (Dipterocarpaceae)	–	+	–	+
	<i>Shorea pinanga</i> (Dipterocarpaceae)	–	–	–	+
	<i>Chaetocarpus castanocarpus</i> (Euphorbiaceae)	+	+	–	–
	<i>Chionanthus sp.1</i> (Oleaceae)	+	–	–	–
	<i>Cratoxylum sumatranum</i> (Hypericaceae)	+	–	–	–
	<i>Diospyros borneensis</i> (Ebenaceae)	–	–	–	+
	<i>Diospyros curranii</i> (Ebenaceae)	+	–	–	–
	<i>Gironniera nervosa</i> (Ulmaceae)	–	–	+	–
	<i>Gluta renghas</i> (Anacardiaceae)	–	+	–	–
	<i>Hydnocarpus polypetala</i> (Flacourtiaceae)	+	–	–	–
	<i>Kayea borneensis</i> (Guttiferae)	+	–	–	–
	<i>Madhuca malaccensis</i> (Sapotaceae)	–	+	+	–
	<i>Palaquium calophyllum</i> (Sapotaceae)	–	–	–	+

Table 3.4 (continued)

Heavy	<i>Palaquium stenophyllum</i> (Sapotaceae)	+	–	–	–
	<i>Scaphium macropodum</i> (Sterculiaceae)	–	+	–	–
	<i>Syzygium tawahense</i> (Myrtaceae)	+	+	+	+
	<i>Allanthospermum borneensis</i> (Simaroubaceae)	–	+	–	–
	<i>Cynometra elmeri</i> (Caesalpiniaceae)	+	–	–	–
	<i>Drypetes kikir</i> (Euphorbiaceae)	–	–	+	–
	<i>Eusideroxylon zwageri</i> (Lauraceae)	–	–	–	+
	<i>Hopea cernua</i> (Dipterocarpaceae)	–	+	+	–
	<i>Hopea semicuneata</i> (Dipterocarpaceae)	+	–	–	–
	<i>Shorea inappendiculata</i> (Dipterocarpaceae)	–	+	–	–
	<i>Teijsmanniodendron coriaceum</i> (Verbenaceae)	+	–	–	–
	<i>Vatica nitens</i> (Dipterocarpaceae)	–	+	–	–

Abundance was defined as the presence of at least 10 stems per hectare on average in the subplots. After each species name it was abundance in the location of study areas in the primary forest site and three selectively logged forest sites: logged 10 years, 5 years, and 1 year ago, present (+) and not present (–).

Plant Functional Types expressed as tree densities

Stems of all PFT classes contributed importantly to tree densities, but there were pronounced differences across the forest types studied (Figure 3.3; Table 3.5).

For the heavy hardwood PFT, abundance of stems was significantly lower in the forest sites selectively logged 1 and 5 years ago than in the primary forest site. The light hardwood PFT class, expressed as abundance of stems, was higher in the forest sites selectively logged 1 year ago than in the primary forest site, with the value for the forest site selectively logged 1 year ago significantly higher than all other forest sites (Table 3.5). The medium hardwood PFT class, expressed as abundance of stems, was significantly less abundant in the forest sites selectively logged 1 and 10 years ago than in the primary forest site; there was no significant difference between the forest site selectively logged 5 years ago and the primary forest site (Table 3.5).

There were no significant differences in species numbers of the light hardwood PFT class between the selectively logged and the primary forest sites (Table 3.5). Generally, the percentage of smaller stems (10–60 cm dbh) in the light hardwood PFT class was low in the primary forest site (c. 15%) but twice as high in the selectively logged forest sites (Figure 3.3a–e). In addition, the percentage of larger stems (> 60 cm dbh) in the light hardwood PFT class was higher in

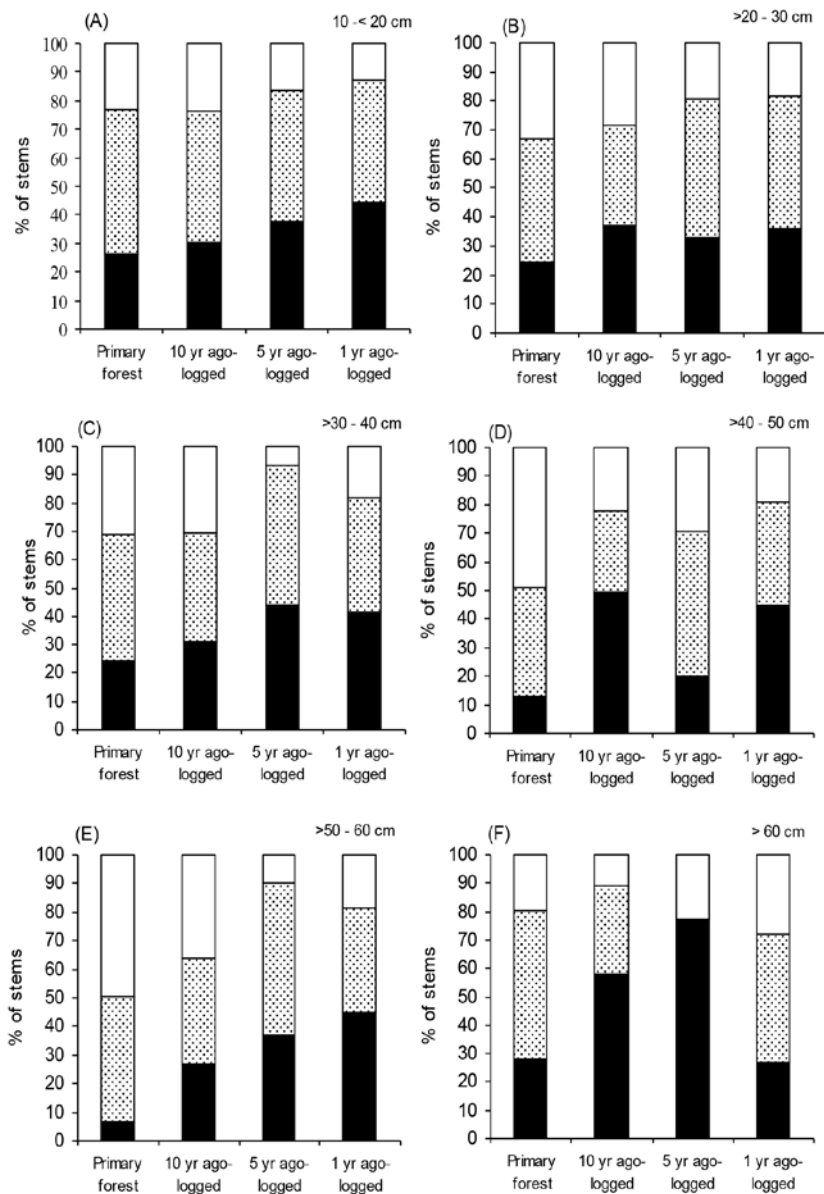


Figure 3.3

The classes of plant functional types light hardwood (solid bars), medium hardwood (cross-hatched), and heavy hardwood (open bars) of stems between 10–<20 cm dbh (A), >20–30 cm dbh (B), >30–40 cm dbh (C), >40–50 cm dbh (D), >50–60 cm dbh (E), and > 60 cm dbh (F) in the primary forest site, and selectively logged forest sites: logged 10 years, 5 years, and 1 year ago.

Table 3.5

Comparison between the plant functional type and species richness (average ± standard deviation) for all tree (dbh ≥ 10 cm) life forms and forest sites.

Plant functional type	Abundance stems (per 100 m ²)				Species (per 100 m ²)				Total species number				
	Primary Forest	Selectively logged forest		Primary forest	Selectively logged forest		Primary forest	Selectively logged forest		Primary forest	Selectively logged forest		
		10 years ago	5 years ago		1 year ago	10 years ago		5 years ago	1 year ago		10 yrs ago	5 yrs ago	1 yr ago
Light hardwood	0.99 ± 1.03	1.29 ± 0.99	1.25 ± 1.11	1.39 ± 1.33	0.97 ± 0.98	1.23 ± 0.91	1.18 ± 1.01	1.25 ± 1.09	53	59	61		
Medium hardwood	1.96 ± 1.44	1.48 ± 1.36	1.55 ± 1.33	1.40 ± 1.28	1.81 ± 1.28	1.34 ± 1.13	1.40 ± 1.19	1.32 ± 1.18	72	44	59		
Heavy hardwood	1.13 ± 1.08	0.95 ± 1.03	0.54 ± 0.82	0.49 ± 0.83	0.90 ± 0.80	0.88 ± 0.93	0.49 ± 0.73	0.43 ± 0.69	22	24	21		

Abundance expressed as densities of stems exceeding 1.3 m in 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 subplots together in the primary forest site and three selectively logged forest sites: logged 10, 5, and 1 year ago, in 10 x 10 m plots, covering a 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)

the forest site selectively logged 5 years ago than in all other forest sites (Figure 3.3f). In the selectively logged forest sites, the dominant species in the light hardwood PFT class were *Alseodaphne elmeri* (Lauraceae), *Barringtonia macrostachya* (Lecythidaceae), *Gymnacranthera farquhariana*, *Horsfieldia polyspherula*, *Knema laurina*, *Myristica villosa* (all Myristicaceae), *Macaranga gigantea*, *Neoscortechinia kingii* (both Euphorbiaceae), *Shorea parvifolia* and *Shorea pinanga* (both Dipterocarpaceae).

The stem abundance in the medium hardwood PFT class was significantly lower in the forest sites selectively logged 1 and 10 years ago than in the primary forest site (Table 3.5). In addition, selective logging did not appear to affect the partitioning of stems across PFT in all forest sites. Only the > 60 cm dbh class in the medium hardwood PFT class was almost completely absent in the forest site selectively logged 5 years ago (Figure 3.3f).

The abundance of stems and species in the heavy hardwood PFT class was significantly lower in the forest sites selectively logged 1 and 5 years ago than in the primary forest sites (Table 3.5). This difference was most pronounced for the percentage of stems (Figure 3.3a-e), whereas for trees > 60 cm dbh the number of stems in the forest sites selectively logged 1 and 5 years ago was higher than in the primary forest site and lower than in the forest site selectively logged 10 years ago (Figure 3.3f).

Discussion

Changes in the forest structure after selective logging

Our study demonstrated that logging had a significant effect on the tree species richness and tree abundance in the diameter class up to 30 cm dbh (Table 3.2, 3.3). Logging did not affect tree species richness and tree abundance in trees >30–70 cm dbh. However, we found that there was a significantly lower number of species and a lower stem abundance for trees >70–80 cm dbh in the selectively logged forest sites 1 and 5 years ago (Table 3.2, 3.3). At larger diameters (>80 cm) dbh values became fuzzy and differences could no longer be detected. This was also reported by Verburg and Van Eijk-Bos (2003). With respect to our finding that logging history did not affect species richness and abundance for trees > 80 cm dbh, we point out that despite the fact that the removal of stems was similar in all selectively logged forest sites, we did observe a difference in the total damage expressed as number of stems between the forest sites selectively logged 1, 5 and 10 years ago (Table 3.1), which was possibly caused by the construction

of skidder roads. The effects of logging intensity could thus largely have been overshadowed by the damage caused by these roads, as has also been reported by Van Eijk-Bos (1996), Verburg *et al.* (2001), Slik and Eichhorn (2003) and Verburg and Van Eijk-Bos (2003). Because no data were available prior to logging, we could not analyze whether tree density in the selectively logged forest sites changed immediately according to the changes in landscape pattern in the recovering forest after logging (Verburg & Van Eijk-Bos, 2003). Our results on the impact of logging on tree species richness are similar to those of other studies carried out during forest inventories in East Kalimantan (Slik *et al.*, 2002; Slik & Eichhorn, 2003; Verburg *et al.*, 2001; Verburg & Van Eijk-Bos, 2003), although a study conducted in the Budongo forest reserve in Uganda showed an increase in species richness following logging activities (Plumtre, 1996).

The number of stems in the >70–80 cm dbh class was clearly affected in some selectively logged forest sites. Nonetheless, the effect of the removal of trees with large stems on forest structure and species diversity was hardly detectable, which could be an indication that diversity in species indices is not a valid tool for measuring the impact of logging in tropical lowland rainforest (e.g. Ter Steege *et al.*, 2002; Slik *et al.*, 2002; Verburg & Van Eijk-Bos, 2003). The impact of logging on tree density, however, depends strongly on the total number of tree stems and species that are removed (Slik *et al.*, 2002; Verburg & van Eijk-Bos, 2003). Although differences between the selectively logged and primary forest sites in stem density were not statistically detectable, based on the lower mean BA values in selectively logged versus primary forest sites, we may conclude that some species could disappear despite selective logging practices (Figure 3.2). The gap phase regeneration hypothesis has recently been under criticism as a mechanism to maintain species diversity due to new empirical evidence that shows tree fall gaps only cause a marginal increase in species diversity. Selective logging provides gaps that might enable light dependent on open places to become established tree pioneer species (e.g. Hubell *et al.*, 1999; Hubell, 2001; Verburg & Van Eijk-Bos, 2003).

Tree species composition in different diameter classes

Our study shows that tree species richness in the 10–<20 cm dbh class was lower in the forest sites selectively logged 5 and 10 years ago compared to the primary forest site, but higher in the forest site selectively logged 1 year ago (Figure 3.2b). Up to 60 cm dbh, the tree species richness was higher in the selectively logged than in the primary forest sites. Although patterns in tree species composition were very difficult to detect, we did find differences in replacement of stems between different wood density classes. Similar to our study, Verburg and Van Ei-

jk-Bos (2003) found a high fraction in the light hardwood class for a number of trees in the smallest diameter class. The higher species richness we found for the dbh class up to 60 cm was associated with the presence of pioneer species, such as the fast growing *Macaranga gigantea*, which were particularly abundant in the forest site selectively logged 10 years ago but absent in the primary forest site (Table 3.4). As was suggested by Slik *et al.* (2002), Slik and Eichhorn (2003) and Verburg and Van Eijk-Bos (2003), the stem recruitment of some pioneer species into the smallest diameter class after logging is most likely the result of the removal of adult tree stems and some species due to the construction of skidding trails or illegal logging activities. The regeneration of tree species in the selectively logged forest sites will mainly determine the prospects for recovery of the original plant diversity. Recently, Arbainsyah *et al.* (2014) found a high tree species richness in FSC candidate, selectively logged forest in East Kalimantan.

Several studies have reported on species composition in tropical rainforest (e.g. Austin, 1977; Newbery *et al.*, 1996; Sheil, 1999; Slik *et al.*, 2002). However, the effects of selective logging on forest structure in terms of the number of tree species per diameter class and plant functional types have rarely been studied. Ward's cluster analysis to separate selectively logged forest sites from primary forest site by the partitioning of life forms (i.e. trees, lianas, fern, shrubs and herbs) was used by Ek (1997) and Arbainsyah *et al.* (2014). They suggest that tree succession in primary tropical rainforest shows a clear intrinsic convergent trend, as was found in Uganda (Sheil, 1999). However, the end stage of this forest succession series was a mono-dominant tree stand which was relatively species-poor. Moreover, in Sheil's (1999) study in Uganda, primary succession was the control site and no replicate plots were used. In our study we did use replicates, but an analysis of tree species richness and tree abundance in the different tree diameter and PFT classes showed that these parameters varied widely across the forest sites considered. This finding suggests that studies involving chronosequences of selective logging may be difficult to interpret, because forest sites with different logging regimes do not necessarily have equal initial states, as shown by our study. This was also reported also by Verburg and Van Eijk-Bos (2003).

Changes in Plant Functional Types after selective logging

Our analyses of the smallest diameter class, < 30 cm dbh, showed a high contribution by the light hardwood PFT class in the abundance of stems from typical pioneer species after logging. Similarly, the abundance of light hardwood stems for > 60 cm dbh was relatively high in forest sites selectively logged 1 and 5 years ago. A delayed recruitment of the medium hardwood PFT class at > 60 cm dbh class was recorded in the forest site selectively logged 5 years ago. This is partly

the result of the differences in the fractions of PFT among logged plots, as has also been reported by Brown and Lugo (1990) and Verburg and Van Eijk-Bos (2003) who described secondary succession in terms of replacement of stems of different PFT classes. The increased contribution of light hardwood types in the selectively logged forest sites was confirmed with the relatively low abundance of medium hardwood stems. The heavy hardwood PFT class was less affected by the history of logging in the selectively logged forest sites. Although these patterns were confirmed by significant differences among the heavy hardwood PFT class in the selectively logged forest sites, they are partly the result of large differences in the classification of PFT among selectively logged forest sites. Secondary succession has also been described in terms of replacement of tree stems of different tree density classes (Brown & Lugo, 1990; Verburg & Van Eijk-Bos, 2003). Similar to our study, several authors found high stem abundances of light hardwood species during the first years of forest recovery succession (Brown & Lugo, 1990; Slik *et al.*, 2002; Verburg & Van Eijk-Bos, 2003).

The primary forest site contained a large density of heavy hardwood stems in the 40–60 cm dbh class, which was mainly the result of high numbers of *Hopea semicuneata* and *Teijsmanniodendron coriaceum*. These species were almost absent in the selectively logged forest sites. The selectively logged forest sites had a larger density of light hardwood stems compared to the primary forest site, including stems of *Shorea parvifolia* (Table 3.4), which is one of the main Dipterocarp timber trees that may have been a target species for logging in Kalimantan (Verburg & Van Eijk-Bos, 2003). In the light hardwood PFT class, trees with large diameters appeared to be affected considerably by logging, while trees with small diameters were still abundant in most of the selectively logged forest sites. Further regeneration of this PFT class depends on available stock of small stems of seedlings and saplings in the selectively logged forest sites (Arbainsyah *et al.*, 2014).

Conclusion

Our study shows that selective logging in tropical rainforests mainly affects the smallest tree stems up to 30 cm dbh, of the forest understorey and mid-levelstorey, and trees with stems between 70 and 80 cm dbh of the emergent trees in the upperstorey, with a clear negative relation between tree stem diameter and plant functional types. Our study showed significant differences between the abundance of tree stems in the small diameter class and in tree species richness in the selectively logged forest sites compared to the primary forest site. Our study revealed marked tree survival patterns, both in relation to stem diameter and PFT class. In the selectively logged forest sites, this PFT related pattern might also

result in selective extinction of certain tree species/genera because of differences in the tree species composition among PFT classes. It is therefore likely that, although tropical rainforests seem to be able to recover from selective logging to some extent, their species composition is altered considerably for a long time after logging took place. Recent evidence from our study area suggests that an undisturbed period of c. 10 years can benefit the recovery of biodiversity within selectively logged forest sites (Arbainsyah *et al.*, 2014). Since tree species diversity remained at an acceptable level throughout the selectively logged forest sites, protection of the primary forests could be worthwhile, especially considering the current rapid loss of primary forests in Southeast Asia.

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