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Stand structure and species composition of merbau in logged-over forest in Papua, Indonesia

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Abstract. *Pamoengkas P, Siregar IZ, Dwisutono AN. 2018. Stand structure and species composition of merbau in logged-over forest in Papua, Indonesia. Biodiversitas 19: 163-171.* Single selective cutting is the most common form of timber extraction in natural forest in the tropics. Although, vast tracts natural forests are already logged-over, the effect of logging on the structure and species composition has been sparsely documented, especially for merbau (*Intsia bijuga*). Merbau is an excellent timber species and intensively harvested in Papua. The objective of this study was to analyze the structure and species composition of merbau in the several logged-over forests at different ages, *i.e*., 1, 5, 11, 16, 21 years old after selective logging and primary forest as the reference plot. The study was conducted in February 2016 at Sarmi District, Papua. The distributions of merbau in each plot varies but when they were compared with that in the primary forest that had reached 9.81%. Thus, the decrease of merbau trees in the plots of logged forest areas was not significant. Index of Diversity of all growth stages was high. In general, the number of merbau seedling regeneration in the study plots are above the average value standardized in Selective Cutting and Replanting System (TPTI) regulation. With regard to the condition of sapling regeneration, we concluded that selective logging might not provide enough growing space for regeneration of merbau. Providing appropriate growing space is one of the key factors to achieve adequate merbau natural regeneration.

Keywords: Composition logged-over forest, merbau, single selective cutting, structure

INTRODUCTION

Compared to the forested area of other islands in Indonesia, Papua is still relatively rich in forests. Papua still hosts vast area of forest-reckoned to cover over 42.2 million hectares. Approximately 40.5 million hectares (96%) of the land area in Papua are forest areas. These forests, covering an area of 21.9 million hectares (51.87%) designated as production forest, 8 million hectares (19.01%) as a conservation area, and 10.6 million hectares (25.25%) as a protected forest. Its land comprises a large mountainous interior, forest lowlands, large areas of coastal mangrove swamps and is surrounded by numerous small islands and coral reefs. There are currently 24 large-scale forest/logging concessions in Papua, covering about 11 million ha (Tokede et al. 2013).

Merbau (*Intsia* spp.) is the dominant timber species in Papua and has been a valuable export commodity because of its strength. As a highly valued commercial tree, merbau is intensively harvested for its timber, as it is one of the most decay-resistant woods known. Over 90% of all logs harvested in Papua are exported to China, wherein the logs are sawn and processed for further export. Therefore, merbau has been a target of exploitation for more than three decades in Papua forests. Industry experts estimate that the majority of the merbau timber in international trade originate in the island of Papua. Until now merbau supply is still fulfilled by deforestation; therefore, it is feared that the practice will threaten merbau availability in nature. Tong et al. (2009) stated that the estimated coverage of merbau in Indonesia is almost 33 Million hectares, with an estimated volume of 6.17 m^3/ha. Merbau was originally found from Eastern Africa, through Southern India, and onwards to Southeast Asia, Oceania and as far as Tahiti; however, today, merbau only exists in significant commercial quantities on the island of New Guinea. The provinces of Papua and West Papua alone had 49.5% of the total merbau in Indonesia in the 1980s.

In tropical rain forests, especially in Indonesia, long-term studies of stand structure and species composition using permanent sample plots are scarce. They are time-consuming, difficult to maintain and very expensive (Sheil 1998). Furthermore, the long-term effects of commercial logging have rarely been studied in the tropics (Finegan 1996). Those studies have been done using chronosequences or *time false series* rather than permanent sample plots.

It is well understood that the decrease and degradation of tropical forests affect not only the production of timber but also the environment. The loss of biological diversity threatens the sustainability and development of forests ecosystem in the future. Maintaining biodiversity has become a global concern and requires the implementation of sustainable management practices at a range of spatial scale (production forests). Many of logged-over forests in Papua still contain enough residual trees to give rise to a sufficient supply of ephemeral seedling stock. The implementation of Selective Cutting and Replanting System, so-called TPTI silvicultural system, should be considered to increase the productivity of logged-over forests and maintaining their biodiversity. In general, selective cutting has caused changes in stand structure and species composition. Stand density decreases after although felling intensity is low. Changes in species composition are characterized by an increased density of regeneration per ha in logged over areas. As logging opens spaces that could provide an opportunity for natural regeneration, it will enrich the composition and species diversity. Although, vast tracts natural forests are already logged-over, the effect of logging on the structure and species composition, and its implication for second cutting cycle have been sparsely documented, especially for merbau (*Intsia bijuga* (Colebr.) Kuntze).

There are two prevailing hypotheses with regard to the response of forests to selective cutting, the intermediate disturbance hypothesis, so-called ID Hypothesis (IDH) (Connell 1978), and the gap-phase regeneration hypothesis, so-called GR Hypothesis (GRH) (Brokaw 1987; Denslow 1995; Denslow and Guzman 2000). IDH describes a unimodal relationship of species diversity to disturbance (Sheil 1999b). IDH in which small-scale (single tree fall) or large-scale disturbances (commercial logging) provide conditions in which a subset of species other than those occupying the undisturbed mature forest, can establish and mature. Such disturbances may lead to higher levels of diversity in comparison with a forest experiencing no disturbance. Similarly, selective logging provides gaps that might enable light-dependent, pioneer species to become established. Thus, according to both IDH and GRH, we expect that selective logging causes a temporary increase in species diversity. The gap-phase regeneration hypothesis describes that selective cutting forms a gradient in term of species recruitment, growth and gap size requirement. Such dissimilarity could maintain some diversity of colonizers (Brokaw 1987)

The objective of the present study was to analyze the structure and species composition of merbau in the primary forest and several logged-over forests aging 1-, 5-, 11-, 16-, and 21-year-old after selective cutting. This research aimed to obtain more comprehensive information about the ecological processes occurred in logged forest areas. The recommendations suggested by the present study would be useful to plan the silvicultural activities for areas low in regeneration and species diversity.

MATERIALS AND METHODS

The study was conducted in February 2016 in the forest cluster of Apauwer River and Tor River (138^{0}05'-139^{0}00' EL and 01^{0}30'-02^{0}30' SL) at Sarmi District, Papua Province, Indonesia. The study location consisted of a primary forest (RKT2016); and 1-year-old (RKT 2015), 5-year-old (RKT 2011), 11-year-old (RKT 2005), 16-year-old (RKT 2000), and 21-year-old (RKT 1995) logged forests. This research was conducted in false time series.

Sampling techniques

The data used in this article were obtained from field research using stratified data. The study site was stratified into 1st strata: purposive data, and 2nd strata: systematic data (Kusmana 1997). Vegetation data were analyzed to find out species density and species composition in each plot. From the above vegetation data, the average height and diameter of the vegetation cover, the vertical and horizontal structure, composition, abundance, diversity, and basal area stand were calculated.

Vegetation analysis

Field data collection utilized for vegetation analysis to determine the structure and composition of stands. Plots used for this study were a combination of paths and terraced lines. Several plots, 20 m x 100 m in size, with 4 replications were established in each logged-over forest. The method of data collection using vegetation analysis is presented in Figure 1.

Data analysis

Data collected in the present study were the number of tree species, diameter at breast height (dbh), total height and bole height. Those field data were used to determine forest stand structure, index of diversity, importance value index, basal area, and for clustering analysis.

Forest stand structure

Data processing was based on the classification of merbau and non-merbau, and the total of all the species. All trees with dbh ≥ 20 cm were measured for diameter, and each was identified for its species. The diameter distribution of residual stand was categorized into class intervals of 5 cm. The distribution was used to create models for forest standing structures, to show the number of trees in these groups per hectare based on their diameter.

Index of diversity

Species diversity expresses the community structure and measures the stability of the community, *i.e.*, the ability of a community to defy change or to rebound from change or remain stable despite the disturbance components on it (Soegianto 1994). Species diversity was presented as the Shannon-Wiener Diversity Index (H'), based on the following formula:

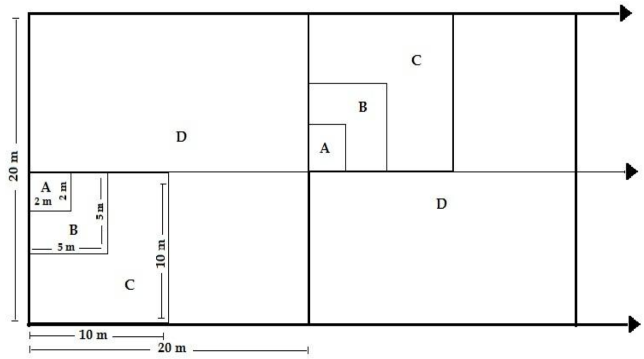

Figure. 1. Illustration of data collection methods for vegetation analysis. (A) at the seedling stage; (B) sapling; (C) pole; and (D) trees stages

$$H' = \sum_{i=1}^{S} [(\frac{ni}{N}) ln (\frac{ni}{N})]$$

Remark:
H' : Shannon-Wiener Diversity Index
S : total species
ni : the total number of one particular species found
N : the total number of individuals found

According to Magurran (1988), the value of Diversity Index ranges between 1.0 to 3.5. H' approaching 3.5 indicates a higher level of diversity.

Importance Value Index

Importance Value Index (IVI) is a quantitative parameter used to express the degree of dominance of a species in a community. Species with the greatest IVI is the most dominant species, or the ruling species. Mueller-Dombois and Ellenberg (1974) stated that the importance value index ranges from 0-300 determined using the following formula:

$$Relative\ Density = \frac{Number\ of\ individual\ of\ the\ species}{Number\ of\ individual\ of\ all\ the\ species} \times 100\%$$

$$Relative\ Frequency = \frac{Number\ of\ occurence\ of\ the\ species}{Number\ of\ occurence\ of\ all\ the\ species} \times 100\%$$

$$Relative\ Dominance = \frac{Total\ basal\ area\ of\ the\ species}{Total\ basal\ area\ of\ all\ the\ species} \times 100\%$$

$$Dominance = \frac{The\ total\ number\ of\ a\ species\ in\ the\ basal\ area}{Total\ area\ sampled}$$

$$Frequency = \frac{Area\ of\ plots\ in\ which\ a\ species\ occurs}{Total\ area\ sampled}$$

Important Value Index (IVI) = Relative density + Relative dominance + Relative frequency

The distribution of seedlings and saplings were not uniform, and according to IVI, the growth rate of seedling and sapling only ranges from 0 to 200. The diameter of seedlings and saplings are small; thus, they are not considered influential on IVI. Therefore, the final formula becomes:

Important Value Index (IVI) = Relative density + Relative frequency

According to Magurran (1988), the diversity index value of species is generally between 1.0 to 3.5. H approaching 3.5 corresponds to increasingly high levels of diversity.

Basal area

The diameter of the tree is used as the growth rate of the basal area (BA). It is one of the important factors to assess the tree growth on subplots. Due to the change in vegetation cover, the growth of BA per hectare was calculated based on the different number of living trees with a diameter at breast height > 20 cm in a plot throughout BA.

Cluster analysis

Cluster analysis identifies objects similar to each other but different from objects in other groups, that can be intellectually satisfying, profitable, or sometimes both. The analysis aims to group a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense or another) to each other than to those in other groups (clusters). Principle clump analysis is based on the size of the proximity or similarity of each individual. Closeness is typically expressed as a dissimilarity function: the less similar the objects, the larger the function values. The Closeness standard used in this analysis is Euclidean distance.

RESULTS AND DISCUSSION

The measurement of vegetation was carried out in 1-year-old (RKT 2015), 5-year-old (RKT 2011), 11-year-old (RKT 2005), 16-year-old (RKT 2000), and 21-year-old (RKT 1995) logged forests; and at the primary forests (RKT 2016) as the reference plot. The phytosociological parameters such as density, frequency, tree stands composition, and dominance for each growth stages-seedlings, saplings, poles, and trees-were calculated.

Stand composition

To see the stand composition of the logged forest (LoA) and the primary forest, the grouping of merbau and non-merbau species was done. The trees composition of the two groups is presented in Table 1.

Table 1. Stand composition of both logged-over forest (LoA) and primary forest

Stand	Stand Density (N/Ha)			Total	Trees Population (%)		Total
	Merbau	Non-merbau	*p-value by t-test*		Merbau	Non-merbau	
RKT*) 1995	15	120	0.000(**)	135	11.11	88.89	100
RKT 2000	8	160	0.000(**)	168	4.95	95.05	100
RKT 2005	20	130	0.000(**)	150	13.33	86.67	100
RKT 2011	7	128	0.000(**)	135	4.94	95.06	100
RKT 2015	5	168	0.000(**)	173	2.88	97.12	100
RKT 2016	17	153	0.000(**)	170	9.81	90.19	100

Note: *RKT = Annual Work Plan. RKT 1995 (21-year-old LoA), RKT 2000 (16-year-old LoA), RKT 2005 (11-year-old LoA), RKT 2011 (5-year-old LoA), RKT 2015 (1-year-old LoA), and the primary forest. ** = *significantly different at p < 0.05*

Table 1 shows the distribution of the trees in the logged-over forests which span from 135 to 173 per ha. The tree distribution variation does not fluctuate. Based on the total number of trees per ha, the contribution of non-merbau species is much greater than those of merbau on all research plots. The contribution of merbau to the total number of trees per ha in logged forest plots ranging from 2.88% up to 13.33% The total number of the merbau population is much smaller compared to that of the non-merbau one which is ranging from 86 to 97%Table 1 also shows that non-merbau dominated the stand composition in all the study plots. In general, the distribution of merbau population in the research plots are relatively balanced, except those in the RKT 2000 (16-year-old LoA), RKT 2011 (5-year-old LoA), and RKT 2015 (1-year-old LoA) plots.

The results showed that the proportion of merbau residual stands in the research plots was lower than that of the non-merbau. The distribution of merbau in each of the plots varies, but when compared to that of the primary forest (RKT 2016), the distribution is relatively less varied which was only 9.81% (Table 1) Thus, the decreased of merbau stands in the plots of the logged forests were not significant. Ecological recovery process occurred as shown in the plot of RKT 1995 and RKT 2005, with a percentage of 11.11% and 13.33%, respectively. Further, it was revealed that the population of merbau stands was predominant in three plots, RKT 1995, RKT 2005 and RKT 2016

The effects of logging on merbau trees (stem diameter at breast height ≥ 20 cm) in the logged forest plots were relatively the same, as reflected in the distribution pattern within all the plots, except those in RKT 1995 and RKT 2005 (Table 1). Merbau species showed low stand population in RKT 2015 (2.88%), RKT 2011 (4.94%) and RKT 2000 (4.95%) (Figure??). This low merbau stand density indicates that the cutting of merbau on the study plots occurred. Nevertheless, according to the regulation of Selective Cutting and Replanting System (TPTI), the number of merbau nucleus tree in the study plots are still more than enough of over 25 trees per ha. The implementation of TPTI aims to regulate natural production forest felling and establishment activities recommending a minimum number of 25 nucleus trees per ha.

The relationship between mean diameter (dbh) and stem number (N) per ha is presented in Figure 2. Figure 2 shows that the relationship between dbh and N on all research plots tend to form a reverse-J shaped curve. This result shows that the larger the size of the tree, the fewer its total number, indicating that the forests are in balanced condition.

The distribution pattern of tree diameters of merbau and non-merbau species is presented in Figure 3. Tree diameter distribution provides the necessary information about tree sizes that indicates successful or failed forest regeneration.

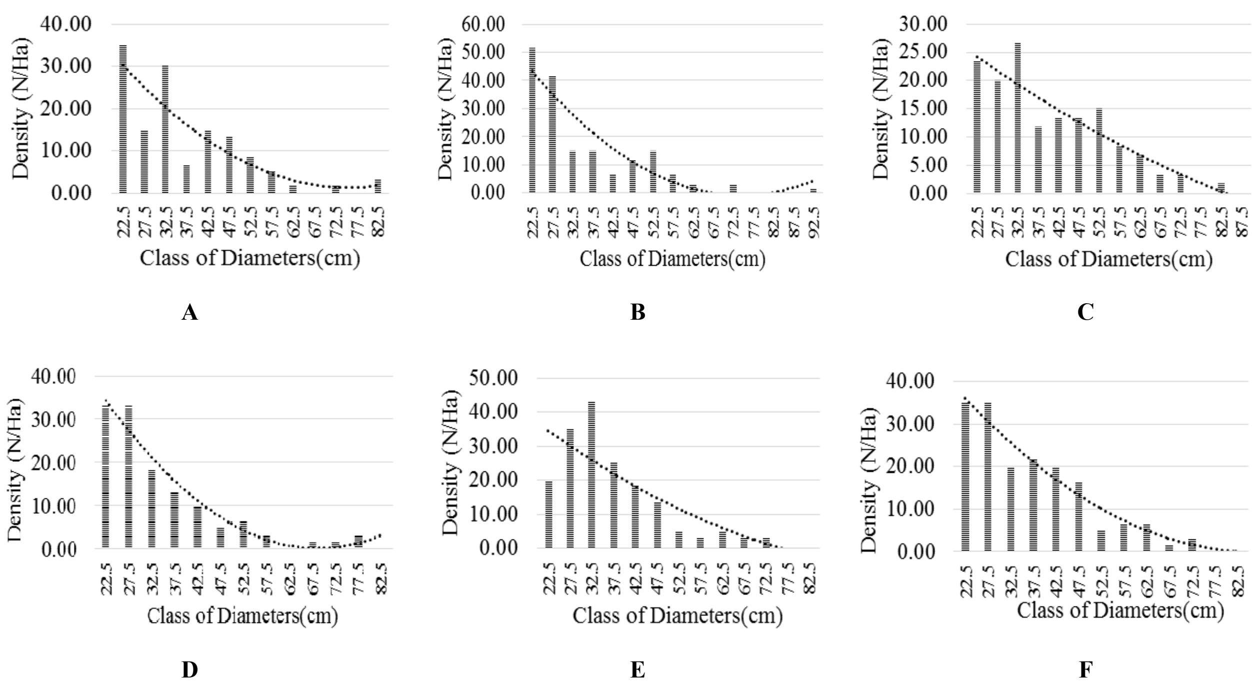

Figure 2. Stand structure of trees in dbh classes (A) RKT 1995, (B) RKT 2000, (C) RKT 2005, (D) RKT 2011, (E) RKT 2015, (F) RKT 2016

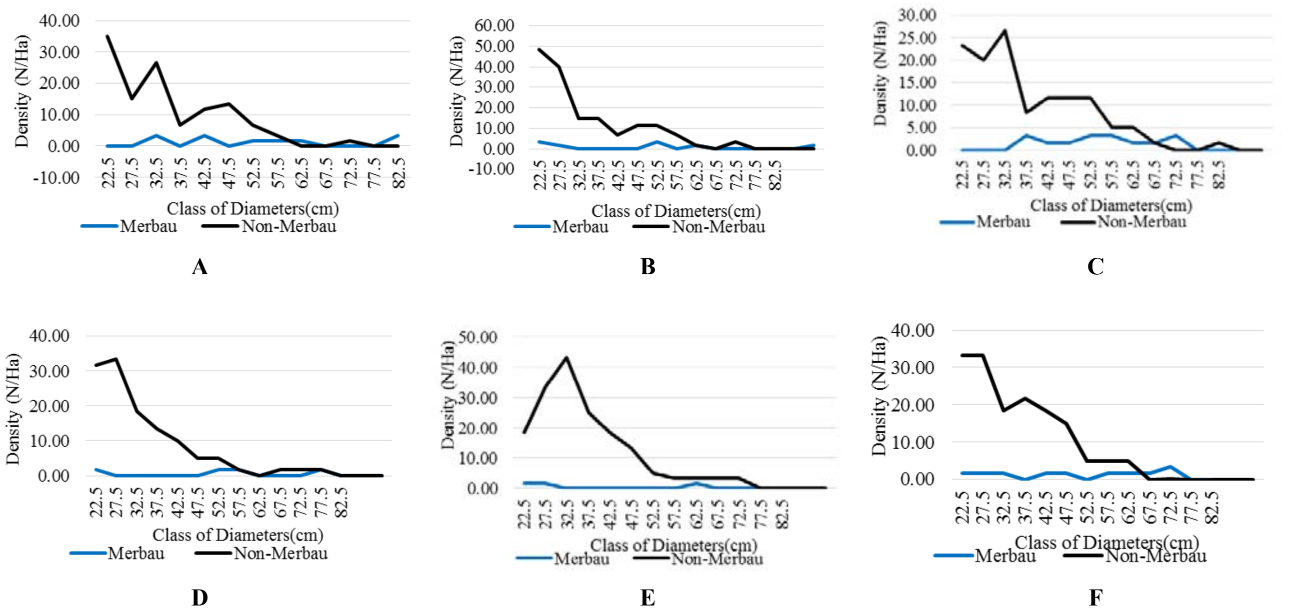

Figure 3. Merbau and non-merbau stand structure in the research plots. (A) RKT 1995, (B) RKT 2000, (C) RKT 2005, (D) RKT 2011, (E) RKT 2015, (F) RKT 2016

Table 2. The top five species with the highest Importance Value Index (IVI) for all growth stages in the study plots.

Tree Species	**Importance Value Index (%)**					
	RKT 1995	**RKT 2000**	**RKT 2005**	**RKT 2011**	**RKT 2015**	**RKT 2016**
Intsia spp.	44.49	20.70	49.28	22.39	9.45	36.06
Pimeleodendron ambonicum	30.42	16.72	24.24	25.69		
Pometia pinnata	26.03	45.69	34.35	55.82	27.82	19.84
Teijsmanniodendron bogoriense	22.99		16.45		35.57	32.89
Pterygota forbesii	23.98				14.99	
Homalium foetidum		31.88				16.80
Celtis latifolia		23.54	17.92	17.12		
Maniltoa sp1.				18.65		
Alstonia scholaris					13.58	
Haplolobus floribundus					11.27	
Myristica fatua						19.91

The success of a species in a particular forest, as well as that of the silvicultural management, can be assessed from the species regeneration success. Studies in many forests showed that each tree species has specific stem diameter distributions. This distribution can serve as the indicator of success or failure of the species regeneration and establishment; hence the population status in a particular forest (Geldenhuys 2010; Everard et al. 1995; West et al. 2000). Stem diameter distribution is a unique characteristic of each tree species, and differs between different species in the same forest stand, with generally the dominant species showing one type of curve and other associated species showing a different curve. Figure 3 shows the static curve of merbau stem distribution, which shows the competitive status of the species in the forest stand. Meanwhile, non-merbau species show an inverse-J shaped curve, indicating dominant species. Many obstacles hinder the regeneration process of merbau in the forest stand; therefore, growing spaces are required for their better natural regeneration.

The top five tree species with the highest Importance Value Index (IVI) for all growth stage in the study plots are presented in Table 2. Table 2 shows that half of the research plots are dominated by *Intsia* spp, except the 1-year-old (RKT 2015), 5-year-old (RKT 2011), and 16-year-old (RKT 2000) logged forests, which are dominated by *Teijsmanniodendron bogoriense* and *Pometia pinnata*. Codominant species found in some research plots are *Pimeleodendron amboinicum* (RKT 1995 and RKT 2011), *Homalium foetidum* (RKT 2000), *Pometia pinnata* (RKT 2005 and 2015), and *Teijsmanniodendron bogoriense* (RKT 2016).

The diversity index of different tree growth stages is presented in Table 3.

Table 3. Diversity Index (H') of different growth stages in all study plots

Stage	Diversity index (H')					
	RKT 1995	RKT 2000	RKT 2005	RKT 2011	RKT 2015	RKT 2016
Seedlings	2.61	3.45	3.41	3.32	3.26	3.00
Saplings	3.75	3.75	3.97	3.99	3.84	3.60
Poles	3.00	2.93	3.22	2.81	2.92	3.12
Trees	3.22	3.29	3.18	3.01	3.40	3.29

Table 3 shows that the species diversity indexes for the tree stage in the study plots are higher than 3, suggesting a high diversity. The diversity of the tree species does not correspond to the age of the logged forest. Overall, the diversity index of each regeneration stages (seedlings, saplings, and poles) are quite high, except that of seedling in RKT 1995, and that of poles in RKT 2011.

Forest regeneration

Forest regeneration is the renewing of tree cover by establishing young trees naturally, promptly after the previous stand or forest has been cut. The method of regeneration, the species, and the standard density are determined to meet the goal of the management unit. Several parameters including the tree diameter at breast height (DBH); and the number of the seedling, sapling, and pole of the species must be determined. Such data are required to decide whether a regeneration in a particular area have met the TPTI requirements for the sustainable management. The number of individual seedling, sapling, and pole have been used as criteria for evaluating the degree of recovery after logging.

Seedling regeneration

Seedling density in the established plots is presented in Table 4. Table 4 shows that within the research plots, the population density of merbau seedling is lower than that of non-merbau seedling. Further, the data show that non-merbau seedling is the largest seedling group in the primary forest (RKT 2016). Within the study plots, the population of seedling regeneration of merbau is lower than that of non-merbau. According to the TPTI regulation, there have to be at least 1000 seedlings per ha left after logging, or in other words the existence of seedlings should spread 40% equally within the forest area in order to the TPTI requirements to be achieved.

Selective logging has a positive influence on the regeneration of seedlings as shown by the higher density of existing seedling regeneration in the logged forest plots (between 14000-26500 seedling ha^{-1}) compared with that in the primary forest or RKT 2016 (13333 seedling ha^{-1}). In general, the number of seedling regeneration for merbau in the study plots were above the threshold required by the TPTI regulation, except those in RKT 2005, RKT 2015 and RKT 2016 which were still below 1000 seedling ha^{-1} (Table 4).

The result is in accordance with the findings of Tokede et al. (2013) who stated that merbau natural regeneration varies according to characteristics of its growing site. In lowland forests of sandy and clayey, the forests generally have a low number of seedling and sapling. merbau natural regeneration varies among growing site, both in terms of the ability to germinate, and the sustainability for future growth. The sustainability of merbau growth depends on the level of the crown cover of other species that grow in association with merbau.

Sapling regeneration

Sapling density fluctuations in the study plots are presented in Table 5. Table 5 shows that the primary forest (2427/ha) has the lowest sapling population among all the plots. Non-merbau predominantly constituted the sapling population in the primary forest. The highest sapling density observed in RKT 2011 (3947/ha). In general, the proportion of non-merbau sapling population was much larger than that of merbau sapling within all the study plots. This low merbau sapling population is presumably caused by the selective logging that does not provide enough space for the merbau sapling to grow freely. Only two plots of RKT whose sapling population exceeded the amount specified by the TPTI standard (240 sapling ha^{-1}), namely RKT 1995 and RKT 2000. Thus, providing more growing spaces for all seedlings is required. However, the overall sapling population density of both merbau and non-merbau species (2427-2947 sapling ha^{-1}) were far higher than that required by the TPTI standard of 240 sapling ha^{-1}. At sapling stage, the non-merbau species still dominate the entire plots. The high abundance non-merbau sapling is triggered by higher sun intensity penetrated through open canopies as a result of selective logging practices (Clark and Covey 2012). Similarly, poles and trees of non-merbau species predominantly constituted the entire research plots. In general, selective cutting might provide growing spaces required for the regeneration of climax species. The intensity of logging negatively affects the presence of tree species in the logged-over forest, impairing the proper species regeneration.

Table 4. Density and species distribution in all study plot

Stands	Stand Density (N/Ha)		Total	Population (%)		Total
	Merbau	Non-merbau		Merbau	Non-merbau	
RKT 1995	1333	25167	26500	5.03	94.97	100
RKT 2000	1500	12500	14000	10.71	89.29	100
RKT 2005	333	14333	14666	2.27	97.73	100
RKT 2011	1000	15500	16500	6.06	93.94	100
RKT 2015	167	21833	22000	0.76	99.24	100
RKT 2016	500	12833	13333	3.75	96.25	100

According to Weidelt (1994), the success of natural regeneration indicates the successful silvicultural technique, sufficient viable seeds availability, and suitable growing condition at the beginning of stage development. Thus, the future development of logged-over forest depends largely on the survival of existing seedlings and saplings, because the establishment of natural regeneration of many species after logging is rather uncertain. In addition, Chazdon et al. (2003) supported the statement of Weidelt (1994) that seedlings and saplings recruitment are affected in part by dispersal limitation. Species lacking tree stage in a secondary forest have a lower abundance of seedling and sapling.

Pole regeneration

Pole density and the fluctuations of the distribution pattern of the study plots are presented in Table 6. Pole regeneration in the logged forest areas with the exception of that in RKT 2005, was lower than that in the primary forest (RKT 2016). The proportion of merbau pole population was far lower compared with that of non-merbau pole within the study plots. Residual stands of merbau were not found in RKT 2011, RKT 2015, and RKT 2016 plots. Total merbau pole population in the study plots was lower compared with the number recommended by TPTI system of 75 poles ha^{-1} after logging. In RKT 2011, RKT 2015 and RKT 2016, merbau pole population were even absent at all. This result indicates that the merbau poles have not regenerated well. Timber stand improvement might be required to allow adequate regeneration and to provide enough space for the merbau pole regeneration. The pattern of merbau regeneration was not clear; thus the trends could not be detected. Large transitions in species composition occur after logging, but the direction of the transitions was not predictable.

We found that the selective cutting of the overstory created numerous canopy openings, increased the light availability, and consequently changed the species composition. This finding is in line with the research conducted by Griffis et al. (2001), and Angers et al. (2005) who stated that the enhancement of light availability induces advanced regeneration, and changes coverage in the understory and eventually affects the species richness of the understory layer.

Basal Area (BA)

As one of the important parameters for stand density, the basal area provides valuable information on the degree of the forest stand recovery. Data on the basal area of the study plots are presented in Figure 4.

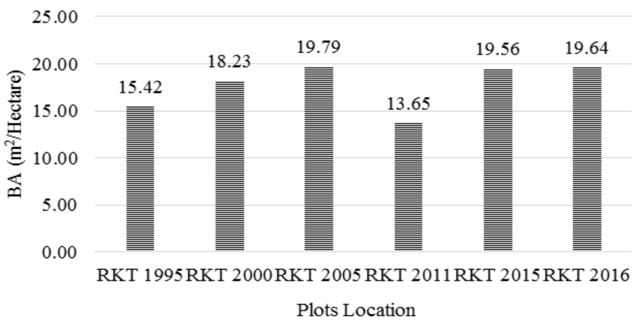

Figure 4. Basal areas in the study plots

Table 5. Sapling density in the study plots

Stands	Stand density (N/Ha)		Total	Population (%)		Total
	Merbau	Non-merbau		Merbau	Non-merbau	
RKT 1995	373	2880	3253	11.48	88.52	100
RKT 2000	347	2826	3173	10.92	89.08	100
RKT 2005	133	2800	2933	4.55	95.45	100
RKT 2011	0	3947	3947	0.00	100.00	100
RKT 2015	187	2906	3093	6.03	93.97	100
RKT 2016	27	2400	2427	1.10	98.90	100

Table 6. Regeneration potential and distribution pattern of pole stage in the study plots

Stands	Stand density (N/ha)		Total	Population (%)		Total
	Merbau	Non-merbau		Merbau	Non-merbau	
RKT 1995	7	206	213	3.12	96.88	100
RKT 2000	7	206	213	3.13	96.87	100
RKT 2005	13	227	240	5.55	94.45	100
RKT 2011	0	200	200	0.00	100.00	100
RKT 2015	0	186	186	0.00	100.00	100
RKT 2016	0	226	226	0.00	100.00	100

Figure 4 shows the effects of logging on trees with diameter at breast height ≥ 20 cm. The total basal area shows a consistent increasing trend over the years. In addition, Figure 4 shows that the plot of RKT 2005 had the largest total basal area of 19.79 m^2 ha^{-1}, surpassing the total basal area in the primary forests (19.64 m2 ha^{-1}).

The total basal area of the logged forests was relatively similar to one another except that in RKT 2011 which only reached 13.65 m^2 ha^{-1} (Figure 4). Comparing the distribution of merbau stands to the total basal area of RKT 2016 (19.64%) which represents the primary forest with logged forest plots, reveals the decrease in the distribution of merbau in the logged forest plots, 7.18% in RKT 2000, 30.49% in RKT 2011, and 0.41% in RKT 2015. This result shows that the selective logging has decreased the population of merbau, but has increased the population of non-merbau species in all logged forest plots. Regeneration conditions depend on the logging intensity and stand condition before logging. This finding is still higher compared with that of the Dipterocarps forests in Central Kalimantan, Indonesia (ranged 3.54% to 15.8%) reported by Pamoengkas (2006).

In our present study, the basal area of the primary forest was 19.64 m^2 ha^{-1}, lower than the average basal area of the entire tropical forests of 30 m^2 ha^{-1} (Weidelt 1994). Other research by Sist and Saridan (1998) stated the basal area of the primary forest in Berau, East Kalimantan was 31.50 m2 ha^{-1}. Noorlaksmono (1993) reported that the basal area of the primary forests of Riau was 29.32 m^2 ha^{-1}. Meanwhile, Riyanto (1995) found that the basal area of primary forest in Jambi was 29.83 m^2 ha^{-1}. In addition, Weidelt and Banaag (1982) also reported that the basal area of Lauan Forest in the Philippines was 33.8 m^2 ha^{-1}.

Grouping of the study plots

The grouping of the study plots was carried out by using cluster analysis. Cluster analysis is a multivariate method to classify a sample of data based on arbitrary "similarities" and "differences" between data observations. The method of hierarchical cluster analysis is best explained by describing the algorithm or set of instructions, which creates the dendrogram results. Any desired number of clusters can be obtained by 'cutting' the dendrogram at the proper level at 3.11 (Figure 5).

Figure 5 shows how the proximity of vegetation communities within the study plots was grouped into three clusters. RKT 1995 and RKT 2005 plots were grouped into cluster I, whereas RKT 2015 and RKT 2016 plots were grouped into cluster II; and RKT 2000 and RKT 2011 were grouped into cluster III.

From the three clusters we revealed the difference in the condition of the vegetation or the regeneration process in the study plots. The density of merbau in cluster I was much higher compared with those in the other clusters. In addition, the pole regeneration of both merbau and non-merbau species in cluster I were relatively similar with those in the other plots, except for that of the merbau which were higher compared with the other plots. Similar situation occurred for the sapling and seedling regenerations. In cluster II, the tree density of merbau and non-merbau were lower compared with that in cluster I, but still higher compared with that in cluster III. The regeneration of merbau at seedling and pole stages in cluster III were still less favorable than those in cluster I and II.

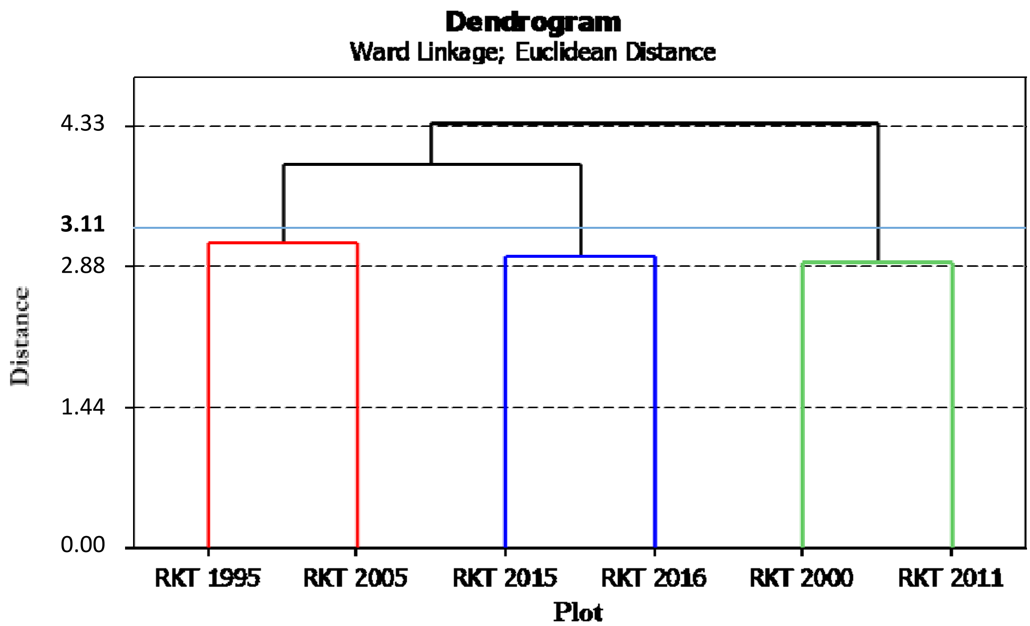

Figure 5. Classification of the research plots

However, the overall regeneration was relatively similar to those in the other plots. The tree density of both merbau and non-merbau species in cluster II were lower compared with those in cluster I, but higher compared with those in cluster III. The seedling and sapling regeneration of merbau in cluster III were less favorable than those in cluster I and II. However, in general the regeneration processes were relatively similar among the study plots.

Based on the present study, we conclude (i) The proportion of merbau in the logged forest areas ranged from 3% up to 13%, while the proportion of non-merbau stands dominated the species composition in those plots. The highest regeneration density and stocking of seedling to pole were exhibited by non-merbau stands, ranging from 88% to 100%. How to improve the performance of the seedlings is an important issue to tackle; thus, the impact of the logging on the regeneration of merbau should be carefully taken into consideration; (ii) Forest management practices, such as provision of space for residual trees of merbau to grow freely should have been planned carefully. (iii) The diversity of seedling, sapling, pole, and tree in the entire plots of the present study were relatively high, indicating that the stability of the forest ecosystems is still well-protected.

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