EFFECT OF POST-LOGGING SILVICULTURAL TREATMENT ON GROWTH RATES OF RESIDUAL STAND IN A TROPICAL FOREST

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ABSTRACT

Post-logging silvicultural treatments are generally performed to improve yields of the remaining tree species by increasing their growth rate. In this study the effects of silvicultural treatment on the growth rates of commercial (dipterocarps and non-dipterocarps) as well as non-commercial tree species in a tropical forest in West Kalimantan were examined and were compared to a control treatment. Silvicultural treatment applied was liberation of future crop trees from lianas and neighbouring competing trees. Treatments were applied to six plots of 80 m x 80 m each. The plots comprised 64 quadrats of 10 m x 10 m to allow better control of measurements. The treatment and control plots were established 6 years after logging. Effects were measured 2, 4 and 7 years after treatment application. In all observation periods, the growth rates increased with silvicultural treatment. Overall, commercial dipterocarps, commercial non-dipterocarps and non-commercial tree species groups differed in response to silvicultural treatment. The growth rates of commercial tree species in plots that received silvicultural treatment were 62–97% higher than in the control plots. For non-commercial tree species, the increase of growth rates was 20–58%, compared to the control plots. These results indicate that the application of silvicultural treatments after logging could help improve the growth of the residual stands. These provide quantitative information that silvicultural treatments in logged-over forest should be considered as a viable management option and may guide the choice of cutting cycle.

Keywords: liberation cutting, sustained yield, TPTI, stand growth, tropical trees

I. INTRODUCTION

A large proportion of Indonesia's natural forests has been logged or has been designed as production forest. The condition of logged-over natural forests differs from that in unlogged (primary) forests. The density of residual trees, saplings and seedlings of commercial tree species in logged-over forest is often low, especially if the forest has been subjected to heavy logging (Adjers *et al.*, 1995). Selective logging operations often damage more than 50% of the stand (Sist *et al.*, 2003), which affect both forest structure and productivity (Pinard and Putz, 1996; Bertault and Sist, 1997; Okuda *et al.*, 2003).

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It is estimated that forest productivity has decreased in the logged-over tropical forests (Silva *et al*., 1995; Dauber *et al*., 2005; Keller *et al*., 2007). Several studies in the logged-over natural forests in Indonesia have reported that commercial trees grow at lower rates than assumed by Indonesian policy-makers when the currently designated cutting cycles were selected (Krisnawati and Wahjono, 1997; 2004; Nguyen-The *et al.*, 1998; Suhendang, 1998). A commonly used silvicultural system to manage natural forests in Indonesia, the Indonesian Selective Cutting and Planting (TPTI) System, assumes post-logging growth in diameter of 1 cm yr^{-1} and defines a cutting cycle of 35 years with a minimum diameter cutting limit of 50 cm for all commercial timber species. With the new regulation system (the Ministry of Forestry Decree No. 11, 2009), all commercial trees above 40 cm in diameter can be felled with a 30-year cutting cycle, which may even increase the risk of depletion of residual stand due to damage created by logging and lower growth of remaining stand. Consequently, the yield (volume harvested) for the next planned harvest at the end of the second cycle may not recover the volume harvested during the first commercial timber harvest.

One alternative to increase volume recovery is to provide improved growth conditions for future crop trees, including high light availability to tree crowns and freedom from lianas. Studies conducted in the tropics have shown that applying silvicultural treatment after logging to future crop trees, such as liberation from competing trees and understorey vegetation can affect significantly their growth rates (Dauber *et al.*, 2005; Wadsworth and Zweede, 2006; Keller *et al.*, 2007). In Indonesia, stand refinement after logging through liberation cuttings has been prescribed under the TPTI System. However, implementation of this treatment in the field (i.e. forest concession area) is widely questioned. In addition, evaluation based on the long-term measurements of stand growth resulted from the application of this practice have rarely been conducted.

The objective of this study were: (1) to analyze the effect of post-logging silvicultural treatment on growth rate of the remaining trees, and (2) to evaluate if trees belonging to commercial dipterocarps, commercial non-dipterocarps and non-commercial species groups respond differently to liberation treatments such as liana cutting and girdling of competing trees.

II. MATERIALS AND METHODS

A. Study Site

This study was conducted at a former forest concession area, logged-over natural forest, located at the Sub-District of Sepauk, District of Sintang, Province of West Kalimantan (0°2’11”N latitude and 111°13’53” E longitude, Figure 1). The average annual precipitation in the region ranges from 2470 to 3460 mm with the highest precipitation occurs in November and the lowest occurs in June. The temperature ranges from 23.4 to 33.7 °C. The altitude ranges from approximately 100 to 200 m above sea level. The topography is mostly undulating and rolling and only small part of the area is flat. The dominant soil type of the study site is red yellow podzolic or ultisols. Minor soil types include latosols. The soils are derived mainly from sedimentary rocks with a very small portion from volcanic materials. The forest stand of the study site is dominated by species of commercial timber group including *Shorea* sp., *Litsea* sp., *Eugenia* sp., *Pometia* sp., and *Dracontomelon* sp. Non-commercial timber species include *Baccaurea* sp. and *Nephellium* sp. The condition of natural regeneration in the study site is generally sufficient in number and spreads evenly, particularly on the area of logging gaps.

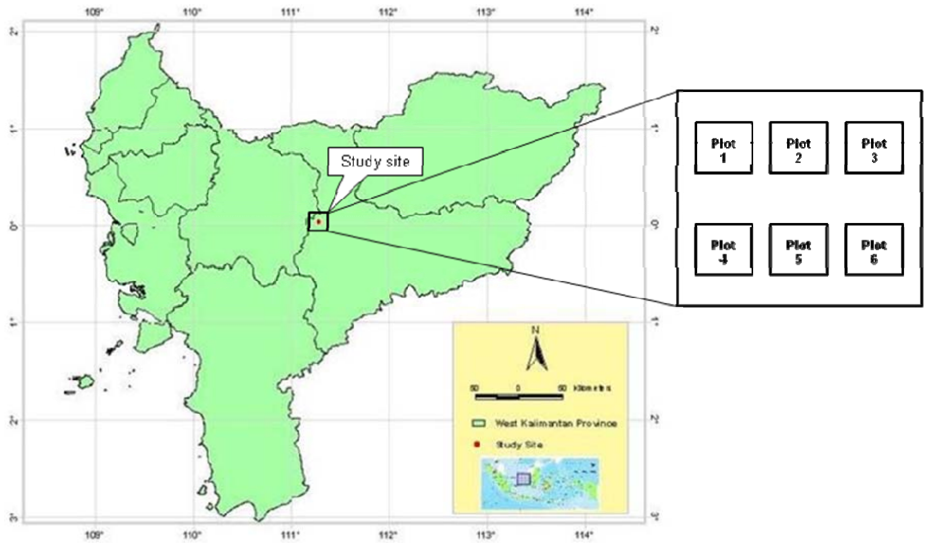

Figure 1. Map of the study site and location of the six experimental plots

B. Experimental Design

The study was carried out in six experimental plots of 80 m x 80 m each (Figure 1). Each plot comprised of 64 quadrats of 10 m x 10 m to allow a better control of measurements. Three plots were selected to receive silvicultural treatment while the remaining three as control plots. The experiment site was logged in 1991/1992 applying a selective cutting system with a minimum diameter cutting limit of 50 cm for commercial timber species. The plot installation and treatment application were conducted in October 1998 at approximately 6 years after logging.

Silvicultural treatment applied was liberation which included cutting lianas and girdling of competing trees on future crop trees. Girdling of competing trees were particularly done to the non-commercial trees of above 10 cm in diameter and poor in condition (e.g. broken, poorly formed, bent, squeezed, etc.), which interfere the growth of future crop trees. Future crop trees were selected from individuals of commercial species that are too small to be harvested in the first cutting cycle (i.e. 20–49 cm in diameter), but they have good form and growth potential and are expected to be harvested in the future. Girdling of competing trees was done by removing the bark and cutting through the cambium with the notches spaced about ± 10 cm apart and 1 m from the base of the tree. The girdling was done to stop or slow the competing trees' growth providing improved condition for future crop trees.

C. Measurement

In each plot, all trees of at least 10 cm in diameter at 1.3 m height (DBH) were marked, mapped, measured and identified to species. Trees were categorized into three different species groups: (1) dipterocarps (e.g. *Shorea* spp., *Dipterocarpus* spp., *Hopea* spp., *Vatica* spp., *Dryobalanops* spp.), (2) commercial timbers other than dipterocarps (e.g. *Agathis* spp., *Durio* spp., *Koompassia* spp., *Dyera* spp., *Palaquium* spp.), and (3) non-commercial timber species (including unknown species). There were more than sixty tree species identified at the plots, 34 of which were considered to be commercial for timber. All plots were first measured immediately after plot establishment and then re-measured at approximately 2, 4 and 7 years after establishment or treatment application, respectively. Dead and newly recruited trees were also recorded during the re-measurement times. Basal area of each plot for each measurement time is presented in Table 1.

Table 1. Basal area (m^2 ha^{-1}) of each plot for each measurement time after treatment

Plot	Immediately after treatment	2 yr after treatment	4 yr after treatment	7yr after treatment
		Control plots		
Plot 1	22.30	23.01	24.11	24.61
Plot 2	28.39	27.68	28.39	27.11
Plot 3	28.25	29.55	31.28	28.19
Average	26.31	26.75	27.93	26.64
		Treatment plots		
Plot 1	24.77	24.72	24.83	25.36
Plot 2	19.01	19.85	20.14	21.09
Plot 3	26.98	28.43	29.49	30.15
Average	23.59	24.33	24.82	25.53

D. Data Analysis

To evaluate treatment effects on growth rates of the remaining trees in three different species groups, a repeated-measures ANOVA was performed with growth rates (GR0-2, GR2-4, GR4-7) as dependent variables, and time, treatment and species group as factors. In this study, the growth rates were defined as mean annual increments in diameter which corresponds to the mean of the difference in diameter between two measurements scaled to one year. Trees with negative growth rates were discarded from the analysis.

To test if trees from different timber species groups (commercial dipterocarps, commercial non-dipterocarps and non-commercial) were affected differently by treatments, a one-way ANOVA was performed, followed by a Student-Newman-Keuls (SNK) test for post hoc treatment comparison. The differences were considered significant at $P < 0.05$. All statistical analyses were done using the SAS/STAT program version 9.1 (SAS Institute Inc, 2005).

III. RESULTS AND DISCUSSION

The average growth rates of the stand in the logged-over forest without additional silvicultural treatment (i.e. control plots) were 0.29 cm yr^{-1} for all species and 0.68 cm yr^{-1} for commercial dipterocarps species (Table 2). These values are similar to the growth rates found in other logged-over forests in the countries, e.g. Nguyen-The *et al.* (1998) in logged-over forest in East Kalimantan and Krisnawati and Wahjono (2004) in logged-over forest in Jambi, although Imanuddin and Wahjono (2005) mentioned an average growth rate of 0.67 cm yr^{-1} (ranging from 0.39 to 1.1 cm yr^{-1}) for all species from permanent sample plots established in several provinces in Indonesia. The variability of the growth rates may be contributed by many factors. Krisnawati and Wahjono (2004) observed that size (diameter) and time after logging application affected the growth rates. Species composition, stand density and crown characteristic may also be important factors contributing to growth (Silva *et al.*, 1995). Other factors may be site quality, topography and microclimate (Oliver and Larson, 1996).

Table 2. Average tree growth rates (cm yr^{-1}) of commercial dipterocarps (*CD*), commercial non-dipterocarps (*CnD*) and non-commercial (*nC*) species group calculated for each measurement period for both treatment and control plots

Growth period	Species group			All species
	CD	*CnD*	*nC*	
		Control plots		
GR0-2	0.62±0.12	0.26±0.03	0.30±0.05	0.27±0.03
GR4-2	0.76±0.27	0.32±0.06	0.34±0.10	0.34±0.05
GR4-7	0.67±0.28	0.28±0.05	0.24±0.05	0.28±0.04
Average	0.68±0.13	0.29±0.03	0.29±0.04	0.29±0.02
		Treatment plots		
GR0-2	0.66±0.12	0.36±0.05	0.24±0.05	0.45±0.04
GR4-2	0.98±0.20	0.48±0.06	0.34±0.05	0.59±0.05
GR4-7	0.75±0.14	0.44±0.06	0.30±0.07	0.54±0.05
Average	0.80±0.10	0.43±0.03	0.29±0.03	0.53±0.03

Approximately 75% of the trees in the control plots had growth rates below 0.4 cm yr^{-1} (Figure 2). During the seven-year observation period, few records of tree growth exceeding 1 cm yr^{-1} were observed in the control plots (i.e. 2.8%); all were represented by the species group of dipterocarps. In the treatment plots, the overall growth rate was 0.53 cm yr^{-1}, which was about twice the growth rate observed in the control plots (Table 2). Trees with growth exceeding 1 cm yr^{-1}, which represented only 2.8% of the stand in the control plots, accounted for 12.6% of all the records (Figure 3). The increase in growth rates in the treatment plots was expected. As a consequence of the growth stimulation created by liberation, 75% of tree growth rates in the stand were distributed below 0.7 cm yr^{-1}, which was almost twice the distribution observed in the control plots, and the proportion of trees with nil growth decreased. During the same observation period, control plots displayed 30% of non-growing trees with growth rates of trees were less than 0.1 cm yr^{-1} (Figure 2) while it was only half (15%) in the treatment plots (Figure 3).

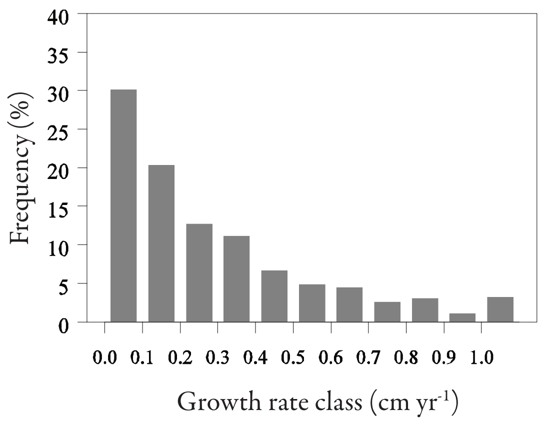

Figure 2. Frequencies of tree growth rates of all species during the seven-year observation period in control plots

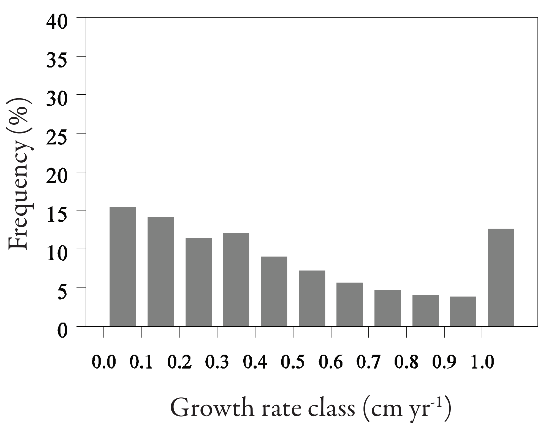

Figure 3. Frequencies of tree growth rates of all species during the seven-year observation period in treatment plots

Analysis of treatment effect on growth rates of the remaining trees indicated that growth rates varied with time after treatment application, treatment and species group (Table 3). On average, growth rates of trees varied through time, with GR2-4 significantly higher (0.48 cm yr^{-1}) than GR0-2 (0.38 cm yr^{-1}) and GR4-7 (0.43 cm $yr^{-1)}$. During the seven-year observation period, trees in all species groups grew faster in the treatment plots than in the control plots (Figures 2-3). Two years after treatment, the growth was enhanced by 67% and it increased 96% 4 years after treatment, which was consistent with the results of other studies (e.g. Maitre, 1985 *in* Nguyen-The *et al.*, 1998). By 7 years after treatment application, however, the average growth rates of trees either in the treatment plots or in the control plots declined, which was probably due to renewed competition.

Table 3. Results of a repeated-measures ANOVA with growth rate as the dependent variable, time as the within-subject variable, and treatment and species group as between subject fixed factors

Test of within-subject effects			Test of between-subject effects		
Factor	*F*	*P*	Factor	*F*	*P*
Time	21.29	**	Treatment	22.63	**
Time x treatment	10.54	**	Species group	27.30	**
Time x species group	11.62	**	Treatment x species group	9.00	**
Time x treatment x species group	9.85	**			

** significance levels: $P < 0.01$; $N = 2754$

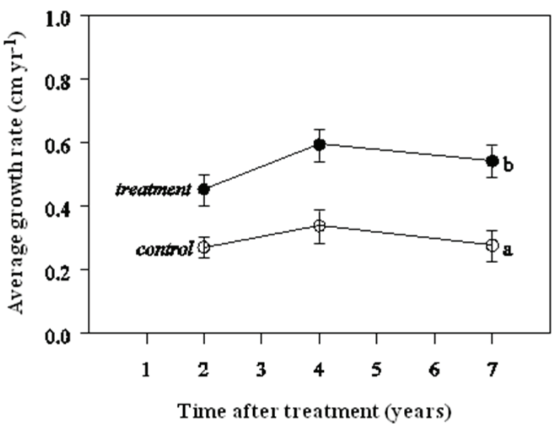

Figure 4. The effect of treatment on tree growth rates for all species. Different letters represent significant differences over time

In regards to species group, tree growth rates varied with species group and, as expected, trees of dipterocarp species group grew faster than the other species groups over the observation period (Figure 5). Within the dipterocarp species (*Dipterocarpaceae* family) itself, various growth rates between genera were observed. The fastest growing dipterocarp genus was *Shorea* (dominated by light-demanding and fast growing species), followed by *Dipetrocarpus* and *Hopea*. This result was consistent with the study conducted by Nguyen-The *et al.* (1998) in logged-over forest in East Kalimantan which found that the genus of *Shorea* grew faster than the other genera. The heterogeneity of growth rates was even greater between species, as also reported by other studies (e.g. Primack *et al.*, 1985; Manokaran and Koscummen, 1987; Appanah and Weinland, 1993).

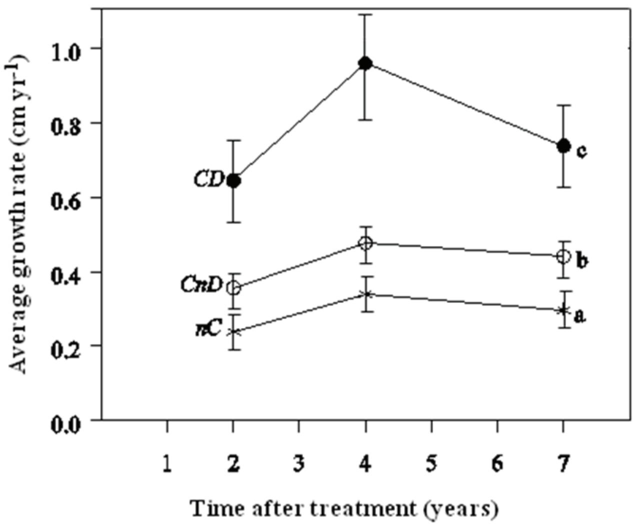

Figure 5. The effect of species group on tree growth rate after treatment application (*CD*: commercial dipterocarps, *CnD*: commercial non-dipterocarps, *nC*: non-commercial). Different letters represent significant differences over time

Trees from three different species groups responded differently to silvicultural treatments, and the interaction between species groups and silvicultural treatment was also significant (Table 3). Trees belonging to the species group of commercial dipterocarps (*CD*) showed the strongest response to liberation treatment with an average growth rate of 0.80 cm yr^{-1}, followed by commercial non-dipterocarps (*CnD*) with an average growth rate of 0.43 cm yr^{-1} and non-commercial (*nC*) species groups with an average growth rate of 0.29 cm yr^{-1} (Table 2, Figure 5). Overall, the growth rates of commercial tree species (*CD* and *CnD*) in plots that received silvicultural treatment were 62–97% higher than in the control plots. For non-commercial tree species, the increase of growth rates in the treatment plots was 20–58%, compared to control plots.

Ignoring potential below-ground effects, the higher growth rates observed in the treatment plots are most likely attributable to the gaps created by trees that were girdled and lianas that were cut to liberate future crop trees and to refine the stand. Consequently, there was higher light availability to tree crowns and lower liana infestation in the light in the treatment plots than in the control plots, which in turn promotes the growth of more light-demanding and fast-growing species (both commercial and non-commercial tree species) as well as pioneer species occupying the stand. Another advantage of applying post-logging silvicultural treatments is that the remaining trees experience better growing conditions after treatment application than when logging operation alone is used (Peña-Claros *et al.*, 2008).

In this study, the better growing conditions were persisted for at least 7 years after treatment application, which were reflected by higher growth rates over time in the treatment plots. The benefits of this treatment was expected to persist for several more years because, after 7 years, the crown exposures might be greater and liana infestations might be lower than in the control plots. De Graaf *et al.* (1999) observed that the benefits of the silvicultural treatments applied in the Surinam rainforests persisted for only about 10 years. They further recommended applying repeated treatments during the cutting cycle to maintain optimal growing conditions. However, Barreto *et al.* (1998) and Holmes *et al.* (2002) were doubtful whether tropical forest managers will be willing to apply additional treatments given their low profit margins and the difficulty in re-establishing access to previously harvested areas.

Although several other studies indicated that tree growth rates are low to secure sustained timber yields after logging in tropical forests, at least using current cutting cycle lengths (Nguyen-The *et al.*, 1998; Dauber *et al.*, 2005; Keller *et al.*, 2007), result of this study suggested that the application of silvicultural treatments after logging could increase growth rates of the remaining trees. Other studies have also found similar findings (e.g. Nguyen-The *et al.*, 1998; de Graaf *et al.*, 1999; Wadsworth and Zweede, 2006). The positive effect of removing lianas and girdling competing trees on the growth rates of future crop trees observed in this study supports the idea that post-logging silvicultural treatments are necessary and effective (Dauber *et al.*, 2005; Keller *et al.*, 2007). These results also provide quantitative information that silvicultural treatments in logged-over forest should be considered as a viable management option and may guide the choice of cutting cycle.

Applying silvicultural treatment after logging would reduce the length of cutting cycle, compared to solely logged forests without additional silvicultural treatment that would require longer cutting cycles. Perhaps the most important consideration to achieving long-term sustainability of managed forests is securing sufficient regeneration of timber tree species to maintain certain degree of genetic variability in targeted tree populations. A combination of silvicultural treatments that improve growth rate and regeneration of the full range of species being managed (not only just species belonging to certain group) would be necessary to apply. In that case the application of silvicultural treatments would need to account for spatial variability of the species.

IV. CONCLUSION

Application of liberation treatment after logging through cutting lianas and girdling competing trees increase growth rates of the remaining trees in the study area of logged-over forest in West Kalimantan. The average growth rates of the residual stand without additional silvicultural treatment were about a half of the growth rates observed in the treatment plots. Growth rates of the remaining trees varied with treatment, time after treatment application and species group.

The positive effect of removing lianas and girdling competing trees on the growth rates supports the idea that post-logging silvicultural treatments should be considered as a viable management option and may reduce the length of cutting cycle. It would be necessary to apply a combination of silvicultural treatments that improve growth rate while securing sufficient regeneration of the full range of species to achieve the long-term sustainability of managed natural forests.

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REFERENCES

Adjers, G., S. Hadengganan, J. Kuusipalo, J. Nuryanto and L. Vesa. 1995. Enrichment planting of dipterocarps in logged-over secondary forests – effect of width, direction and maintenance method of planting line on selected *Shorea* species. Forest Ecology and Management 73: 259–270.

Appanah. S. and G. Weinland. 1993. Planting quality timber trees in Peninsular Malaysia – a review. Malaysian Forest Record No. 38, Forest Research Institute Malaysia, Kuala Lumpur. 247p.

Barreto, P., P. Amaral, E. Vidal, and C. Uhl. 1998. Costs and benefits of forest management for timber production in eastern Amazonia. Forest Ecology and Management 108: 9–26.

Bertault, J.-G. and P. Sist. 1997. An experimental comparison of different harvesting intensities with reduced-impact and conventional logging in East Kalimantan, Indonesia. Forest Ecology and Management 94: 209–218.

Dauber, E., T.S. Fredericksen, and M. Peña-Claros. 2005. Sustainability of timber harvesting in Bolivian tropical forests. Forest Ecology and Management 124: 123–135.

De Graaf, N.R., R.L.H. Poels, and R.S.A.R. van Rompaey. 1999. Effect of silvicultural treatment on growth and mortality of rainforest in Surinam over long periods. Forest Ecology and Management 124: 123–135.

Holmes, T.P., G.M. Blate, J.C. Zweede, R. Pereira, P. Barreto, F. Boltz, and R. Bauch. 2002. Financial and ecological indicators of reduced impact logging performance in the eastern Amazon. Forest Ecology and Management 163: 93–110.

Imanuddin, R. and D. Wahjono. 2005. The utilization of growth and yield data to support sustainable forest management in Indonesia. *In*: Priyadi, D., P. Gunarso, and M. Kanninen (Eds.), Permanent Sample Plots: more than just forest data. Proceedings of the International Workshop on Promoting Permanent Sample Plots in Asia and Pacific Region. Bogor, Indonesia, 3-5 August 2005. Pp. 87–94.

Keller, M., G.P. Asner, G. Blate, J. McGlocklin, F. Merry, M. Peña-Claros, and J. Zweede. 2007. Timber production in selectively logged tropical forests in South America. Frontiers in Ecology and the Environment 5: 213–216.

Krisnawati, H. and D. Wahjono. 1997. Residual stand structure and diameter increment of swamp natural forest in Riau: a review (in Indonesian). Proceedings of the National Discussion on Swamp Forest Management and Expose on the Forestry Research Results in Sumatra. Medan, 18-19 September 1997. Pp. 55–68.

Krisnawati, H. and D. Wahjono. 2004. Stand diameter increment of logged-over natural forest in the Province of Jambi (in Indonesian with English abstract). Journal of Forest and Natural Conservation Research 2: 156–166.

Manokaran, N. and K.M. Kochummen. 1987. Recruitment, growth and mortality of tree species in a lowland dipterocarp forest in Peninsular Malaysia. Journal of Tropical Ecology 3: 315–330.

Nguyen-The, N., V. Favrichon, P. Sist, L. Houde, J-G. Bertault, and N. Fauvet. 1998. Growth and mortality patterns before and after logging. *In*: Bertault, J-G and Kadir, K. (Eds.), Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantan. Joint publication of CIRAD- forêt, FORDA and PT. INHUTANI I. Pp. 181–216.

Okuda, T., M. Suzuki, N. Adachi, E.S. Quah, N.A. Hussein and N. Manokaran. 2003. Effect of selective logging on canopy and stand structure and tree species composition in a lowland dipterocarp in Peninsular Malaysia. Forest Ecology and Management 175: 297–320.

Oliver, C.D. and B.C. Larson. 1996. Forest Stand Dynamics. McGraw-Hill, New York. 544p.

Peña-Claros, M., T.S. Fredericksen, A. Alarcón, G.M. Blate, U. Choque, C. Leaño, J.C. Licona, B. Mostacedo, W. Pariona, Z. Villegas and F.E. Putz. 2008. Beyond reduced-impact logging: silvicultural treatment to increase growth rates of tropical trees. Forest Ecology and Management 256: 1458–1467.

Pinard, M.A. and F.E. Putz. 1996. Retaining forest biomass by reducing logging damage. Biotropica 28: 278–295.

Primack, R.B., P. Ashton, P. Chai and H.S. Lee. 1985. Growth rates and population structure of *Moraceae* trees in Serawak. East Malaysia. Ecology 66: 577–588.

SAS Institute Inc. 2005. SAS/ETS User's Guide, Version 9.1. SAS Institute Inc, Cary, NC. 2416p.

Silva, J.N.M., de Carvalho, J.O.P., Lopes, J do C.A., de Almeida, B.F., Costa, D.H.M., de Oliveira, L.C., Vanclay, J.K., and Skovsgaard, J.P. 1995. Growth and yield of a tropical rainforest in the Brazilian Amazon 13 years after logging. Forest Ecology and Management 71: 267–274.

Sist, P., R. Fimbel, D. Sheil, R. Nasi and M.-H. Chevallier. 2003. Towards sustainable management of mixed dipterocarp forests of Southeast Asia: moving beyond minimum diameter cutting limits. Environmental Conservation 30: 364–374.

Suhendang, E. 1998. Measuring diameter increment of meranti (*Shorea* spp.) at the logged-over forest. Paper presented in the Stand Growth and Yield Discussion. Bogor, 8 April 1998 (in Indonesian).

Wadsworth, F.H. and J.C. Zweede. 2006. Liberation: acceptable production of tropical forest timber. Forest Ecology and Management 233: 45–51.