Evaluation of the sustainability of a logging system consisting of selective logging and line planting in Indonesia
（インドネシアにおける択伐と列状植栽を組み合わせた施業の持続可能性の評価）

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The forest cover in Indonesia is decreasing due to the logging and poor regeneration of dominant dipterocarp species. The resulting drop in productivity from desired species creates forests with low commercial value and induces land-use changes. Therefore, to maintain the forest area, it is important to preserve the level of productivity by desirable *Shorea* species (Dipterocarpaceae family). To promote the regeneration of desirable species, reduced-impact logging (RIL) and an enrichment line planting system have been installed in some forest areas; however, their effectiveness has not been evaluated. In this study, we assessed the efficiency of RIL and a line planting system for the regeneration of useful species in a logged-over forest.

This study was conducted in an active logging concession in Central Kalimantan, Indonesia. In this concession, both RlL and a line planting system have been in use since 1999.

1. Evaluation of the production sustainability of line planting system from the comparison of 10-years logged-over dynamics under different logging systems

Stand dynamics after conventional logging (CL), reduced-impact logging (RIL), and RIL followed by enrichment line planting and annual slashing (RIL+LP/S) were monitored for 10 years in three plots (1 ha each) in each of the three sites in the concession. All trees >10 cm diameter at breast height (DBH) and all planted *Shorea johorensis* were monitored for survival and growth. The rate of natural recruitment of poles (i.e., trees >10 cm DBH) of *Shorea* spp. was low in the CL site, intermediate in the RIL site, and high (46±29.5 trees/ha) in the RIL+LP/S site. The growth of non-planted trees followed the same trend, presumably due to the proliferation of pioneer trees in the CL site and lack of slashing and line clearing in the RIL site. Ten years after treatment, 78% of the planted seedlings were still alive. Although line planting increased the stock of desirable *Shorea* spp. relative to RIL alone, the enhanced light conditions brought about by strip cutting for line planting and the slashing of non-commercial understory plants and lianas

increased natural regeneration significantly. To ensure sustainable productivity, either line planting or slashing would be appropriate in logged-over forests. In terms of cost, line planting is recommended to enhance the recruitment of commercially desirable species. The selection of an appropriate silvicultural treatment should depend in part on the post-logging abundance of desirable species and the costs associated with line planting and slashing.

2. Effect of selective logging and line planting system on the forest understory condition

The large canopy opening and high light conditions in logged-over forests promote invasion by pioneer species and reduce the commercial value of the forest area. In the study site, reduced impact logging (RIL) has been applied to mitigate the effects of logging, and line planting of useful species has been conducted. However, quantitative assessments of canopy openness in response to RIL and line planting are lacking.

At the study site, 3-m wide strip cutting lines were implemented. The effects of this practice on canopy openness are poorly understood. This study assessed the effects of different logging systems on light conditions using hemispherical photographs taken in plots set in a primary forest, a forest logged using RIL, and a forest treated with strip cutting after RIL. Photographs were also taken at the center of the strip cutting lines. A comparison of canopy openness among the natural forest and two logged-over forests subjected to different logging treatments revealed that logging activity had significant effects on the light conditions in the area. High levels of canopy openness were found along skid trails and logging gaps following the trails. Therefore, reducing the impact on light conditions should be considered when planning skid trails. There was no significant difference in mean canopy openness between the logged-over forest plots with and without strip cutting lines; however, strip cutting affected the sunfleck duration on the forest floor. This could impact seedling recruitment under different light conditions in selectively logged forests. In addition, there were large differences in canopy openness along each line, which could cause variation in the growth of planted trees.

3. Effects of contrasting selective logging managements in the light environment and line-planted seedlings

We monitored the changes in light conditions among a primary forest and two managed forests with or without line planting after reduced-impact logging (RIL). In the study site where line planting was applied, the correlation between light conditions and line-planted seedling growth was assessed. Light conditions were monitored by hemispherical photography for 31 months immediately after logging and strip cutting for line planting. The locations were classified as skid trails, logging gaps, and planting lines. After logging, the canopy openness (CO) increased in both of the managed forests (significant differences were not found between the two sites). For each disturbance element, greater CO was detected in the skid trails and logging gaps than in the planting lines. After 31 months, the mean CO in each managed site decreased significantly due to pioneer seedling establishment. Invasion by pioneer species inhibited planted seedling growth. Additionally, there was a significant difference between the two sites managed by line planting 31 months later. Although the CO value in the logging gap and skid trail decreased to the value in the location protected from logging, the CO values in the planting lines were higher than the values obtained from the skid trails and logging gaps. Therefore, setting planting lines may influence forest dynamics by maintaining CO.

4. Neighboring tree effects on the survival and growth of line-planted *S. johorensis*

Enrichment line planting of valuable *Shorea* species has taken place in logged forests to sustain the timber yield. However, scant information is available regarding the effectiveness of this method. Neighboring trees along planting lines may compete with and affect planted trees. We assessed the survival, growth, and crown exposure of planted trees to evaluate the effect of neighboring trees in three (1 ha) plots in which *Shorea johorensis* seedlings had been planted in strips 3 m wide and 5 m apart along five parallel north-south lines separated by 25 m each. The planted trees were monitored for 11 years after planting. Crown exposure was evaluated using a three-dimensional spatial model with *SExI-FS* software. Eleven years after planting, 77.6% of the planted *S. johorensis* had survived. The average diameter at breast height (DBH) was 16.7±5.6 cm (range, 5.3–33.6 cm). The initial growth 1 year after planting predicted the variance in DBH 11 years later.

Trees showing rapid initial growth exhibited higher survival and growth rates in subsequent years. The variation in light conditions in the planting lines affected the initial and subsequent growth and survival rates. The spatial model illustrated how neighboring tree crowns suppress the growth of planted trees by casting shade. In a line planting system, neighboring trees affect the survival and growth of planted trees; however, this can be reduced by treating the canopy to ensure the exposure of planted trees to sunlight.