International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:7, No:7, 2013

Light Condition Change by Different Logging Systems in Lowland Dipterocarp Forest

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***Abstract*—**In a lowland dipterocarp forest, we assessed the impact of canopy openness (CO) and the resultant changes under different logging systems using hemispherical photography. CO was assessed in a primary forest and two forests logged selectively using reduced impact logging. At one site, 3-m-wide strip cutting was conducted for line planting. From the comparison of CO among the three sites, we found significant changes caused by logging. However, no significant difference was observed between the two logged sites. Strip cutting treatment did not affect CO. One year after, significant canopy closure occurred in both of the logged sites. Canopy closure was significant regardless of the disturbance element, logging gap, skid trail, or strip cutting line. Significant establishment of seedlings within a year was observed in the strip cutting line. Seedling establishment seemed to contribute to rapid canopy closure and prospected to affect to the survival and growth of planted trees.

***Keywords*—**Hemispherical photography, light condition, lowland dipterocarp forest, selective logging.

I. Introduction

In tropical Southeast Asia, the primary forest type is lowland dipterocarp forest. The forest is dominated by *Dipterocarpaceae*, which compose the main canopy layer [1]. However, the dipterocarp forest is the most threatened forest in the area [2]. In Borneo, forest loss has been significant, and the area covered by these forests has shrunk to about half its size over the last 50 years, with further loss anticipated [3].

The main cause of forest loss is the targeted logging of dipterocarps, the main commercial species, and logging activities change the forest environment dramatically. Typically, the removal of canopy trees and the activities of bulldozers in logging activities alter light conditions significantly [4]. Light condition is one of the main factors determining forest dynamics. The light conditions change and seedling establishment determine the following dynamics [5]. Generally, after logging, species of the genus *Macaranga*, the main pioneer species, invade to the logging gaps [6]. They are light-demanding and their responses to light condition change rapidly. This invasion delays forest succession and the regeneration of dipterocarps. From a commercial perspective, such low commercial value forests dominated by pioneers will be abandoned and converted to agricultural usage or plantation, which is a main cause of forest loss in Southeast Asia. Thus, an urgent need exists to establish sustainable management that enables conservation through use [7]. In recent years, to achieve such sustainable management, reduced impact logging (RIL) methods have been applied in some production forests. RIL was designed to reduce the impact of logging based on planning and the training of workers [8], and was expected to suppress pioneer invasion and accelerate the regeneration of logged forests by reducing damage from logging.

Moreover, in Indonesia, new logging systems composed of selective logging and line planting have been utilized in recent years [9]. In this system, the line planting of useful species is conducted to sustain productivity. In many cases, species of the genus *Shorea* belonging to the *Dipterocarpaceae* family are used [10]. In the line planting system, strip cutting was conducted after selective logging. In the 3-m-wide planting line, all plants excluding commercial species are removed to enhance the light conditions of seedlings. Although moderate sunlight is important for planted trees [11], [12], such additional cutting may induce further light condition changes.

However, the quantitative assessment of light conditions in the forest under RIL and line planting systems has not been conducted. Furthermore, trees around the gap will respond rapidly to these changes in light conditions. To grasp the effects of different logging systems on light conditions, assessing the temporal light condition changes after logging is important. In this study, we assessed the light condition changes in the forest under different logging systems, specifically RIL and the line planting system. Light conditions were assessed by hemispherical photography.

II. Materials and Methods

A.Study Site

This study was conducted in a logging concession located in Central Kalimantan province, Indonesia (00º36'–01º10'S, 111º39'–112º25'E; Fig. 1). The concession has been managed by logging company PT. Sari Bumi Kusuma. The forest type is lowland dipterocarp forest. In the concession, selective logging using RIL methods targeting dipterocarps has been conducted, and the line planting of desired *Shorea* species has been applied in some areas.

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Fig. 1 Concession map of the study area

B.Plot Setting

To assess the impact of logging and strip cutting treatments, three sites were selected for hemispherical photography. Primary forest was chosen as a control (site PF), and two logged forests were chosen for this study. One was logged at the stand level by selective logging using RIL methods (site S). The other site was treated with 3-m-wide strip cutting following selective logging with RIL (site SL). The difference in slope position was within about 20m, except for two plots at sites PF and S (Table I).

TABLE I
TOPOGRAPHY AT EACH SITE

Plot	Difference in slope position (m)	Slope aspect
PF 1	11.8	South
PF2	13.9	Ridge from North to South
PF3	31.5	Southeast
S1	15.8	Northwest
S 2	21	South east
S 3	15	South
SL1	20	Northwest
SL2	16.5	Northwest
SL3	12.4	East
Strip cutting line 1	14.4	South
Strip cutting line 2	9.9	North
Strip cutting line 3	1	Almost flat

PF, primary forest; S, selective logging; SL, selective logging and line planting

At SL, 3-m-wide strip cutting was conducted at 20–25-m intervals from north to south for planting. In the lines, all of the trees excluding commercial species and understory plants were clearly removed. No canopy treatments such as girdling or pruning were performed. At each of the three sites, three 50 × 50-m quadrates were placed at random for hemispherical photography. At the PF site, plots were chosen in stands with closed canopies. At both of the logged-over sites, trails from logging activities, skid trails, logging gaps, and strip cutting lines were mapped in all plots. Skid trails traversed by bulldozers were approximately 3–4 m wide (Fig. 2).

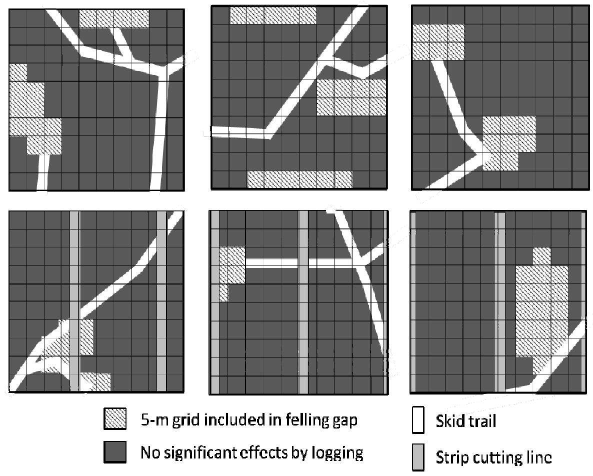

Fig. 2 Plot map including logging trails at sites S and SL. The top three maps indicate the three plots at site S, and the lower three maps indicate the three plots at site SL

C.Hemispherical Photography and Image Analysis

Hemispherical canopy photography is widely used to assess light conditions [13]–[16]. Hemispherical photographs were taken in October 2011, before planting, and about a half year after logging. One year later, in October 2012, we assessed temporal changes in canopy openness (CO).

Within a quadrate plot, 49 photography points were taken at a 5-m spacing. These 5-m grids were located in the interior of the plot, 10m from the plot boundary, to avoid the inclusion of canopy of trees and logging effects located outside the plot. In addition, three strip cutting line transects were chosen near the plots at the SL site. In a strip cutting line, hemispherical photographs were taken at a 5-m spacing for 100m; therefore, 21 photographs were taken per line. In total, nine plots and three line transects were established (Fig. 3).

Photographs were taken according to the Open-sky Reference Method (ORM) proposed by Tani [17]. The photography equipment included a digital camera (Coolpix 8400; Nikon, Tokyo, Japan) with an attached fisheye converter FC-E9 0.2× lens (Nikon). The camera was mounted on a tripod, and the lens was set at a height of 1.2m. From the photographs, we calculated CO using Gap Light Analyzer (GLA) Ver. 2.02 [18]. This software has been used in several studies [19]. The GLA software changes photographs to binary images of ‘sky’ or ‘not sky’ based on thresholds that refer to an open-sky condition, according to ORM methods. CO was measured in each of the three sites. As a result, 147 image sets for each site and 63 image sets for cutlines were analyzed.

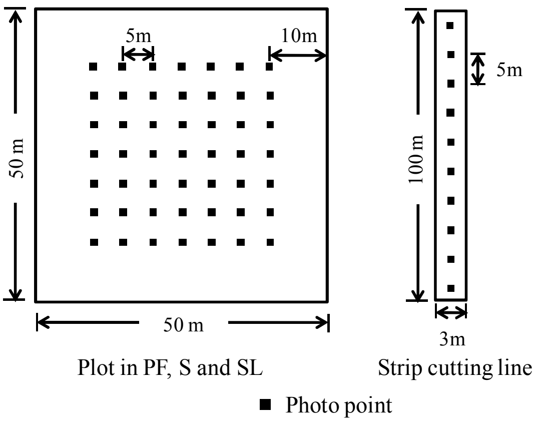

Fig. 3 Photography schematic of plot and line transects

D. Tree Census

At each site, a tree census was conducted in 2011, after logging. The monitoring plots established at the PF, S, and SL sites measured 4.00, 2.25, and 3.00ha, respectively, and the respective basal areas of trees >10cm were 32.0, 22.9, and 18.5m^2/ha. In the strip cutting line, line transects (20 × 100m) were set along the line and we recorded the position of trees in 2011 and seedling recruitment (growth to 1cm DBH) for 1 year until 2012.

E. Statistical Analysis

To evaluate the effects of logging and strip cutting treatment on canopy openness, statistical differences in the mean CO among the three sites and the strip cutting lines were assessed using the Kruskal–Wallis test. When a significant difference was observed in the mean CO, we conducted a multiple comparison using the Steel–Dwass method. To compare the CO in logging year and 1 year after logging, we compared the mean CO using the Mann–Whitney *U*-test.

In addition, from the plot maps, we separated all the photo points into the elements of disturbance, including intact, skid trail, logging gap, and strip cutting line (site SL only). We then compared the CO among these elements using one-way analysis of variance (ANOVA). When statistical differences were detected, multiple comparisons were conducted by Tukey's method. Statistical differences were detected, with $P<0.05$ determined as being statistically significant.

III. Results

A. Change in Canopy Openness for Each Site

Mean CO values measured in the 2011 logging year were 1.6 ±0.9%, 7.6 ±6.6%, and 7.9 ±6.6%, at the PF, S, and SL sites, respectively. In the strip cutting line, the mean CO was 11.7 ±6.6%. A statistical difference was observed among the three sites and the strip cutting line. From multiple comparisons using the Steel–Dwass method, the mean CO was the highest in the strip cutting line. The mean CO at the PF site was statistically low compared to both of the logged sites and the strip cutting line. Significant effects of logging activities were detected. However, no significant difference was noted between the S and SL sites, and strip cutting had no significant effect on the light condition. In 2012, 1 year after logging, the mean CO at the PF site changed to 1.8 ±1%. No significant change in the mean CO was observed at any of the sites.

However, a significant a reduction in CO occurred at both the two logged sites and the strip cutting line according to a Mann–Whitney *U*-test. The CO decreased to 3.2 ± 2.5%, 5.1 ± 4.4%, and 9 ± 5.9% at sites S, SL, and the strip cutting line, respectively (Fig. 4). One year later, the highest mean CO was still found in the strip cutting line, and a statistical difference was detected between sites S and SL.

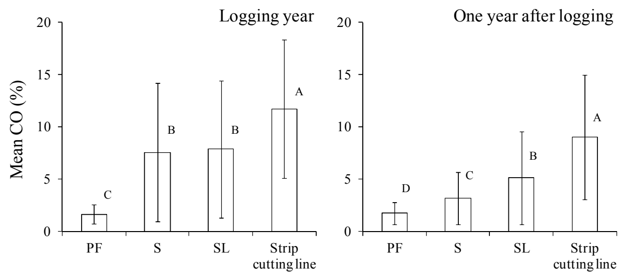

Fig. 4 Mean CO at each site and strip cutting line. Bars denote the mean CO measured in logging year and 1 year later. Different letters indicate a statistical difference

Fig. 5 shows the frequency distribution of CO and the change after 1 year at each of the three sites including the strip cutting line. At both of the two logged sites, sites S and SL and strip cutting lines, the initially higher CO decreased and the peak shifted to a lower CO class. The decrease in frequency was significant in the higher CO class (16–32%), while the frequency increased in the lower CO class (<8%). The distribution did not change in site PF.

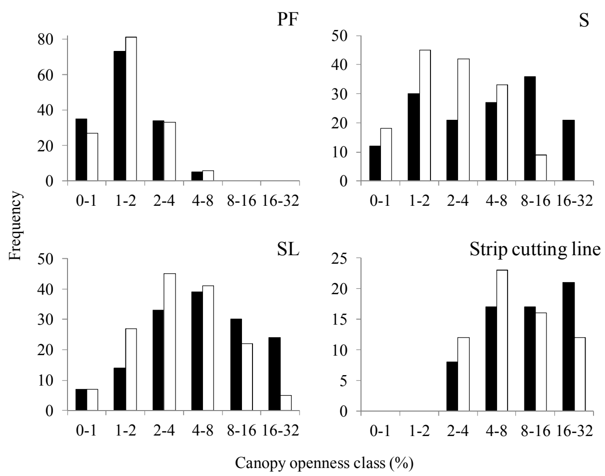

Fig. 5 Change in the CO distribution for 1 year after logging in each of the three sites including the strip cutting line using two fractional scales

B.Change in Canopy Openness for Each Disturbance Element

Fig. 6 shows the mean change in CO under each disturbance element over 1 year at the S and SL sites. One year after logging, a significant change in light conditions occurred. A statistical reduction in CO was found for each element, including skid trail, logging gap, and strip cutting line, at both of the two logged sites. At site SL only, a statistical reduction in the area intact after logging was found.

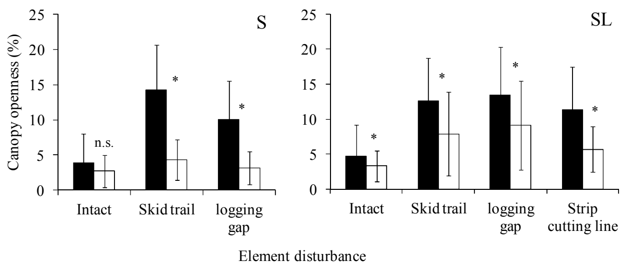

Fig. 6 Mean CO change under each disturbance element. Blank bars express the mean CO in the logging year. Filled bars express the mean CO 1 year after logging, and asterisks indicate a statistical difference

C.Light Condition Changes in the Strip Cutting Line

In each strip cutting line, a large variation in CO was observed after treatment in 2011 (Fig. 7). These results suggested a variance in the efficiency of strip cutting in terms of light condition change. Light conditions in the gap were affected by surrounding trees [20], and under the same 3-m-wide strip cutting treatment, the effects on light condition fluctuated. After 1 year, a difference was noted in the reduction of CO in the line. In 2012, a large reduction was found in the photo points compared to the large CO measured in 2011.

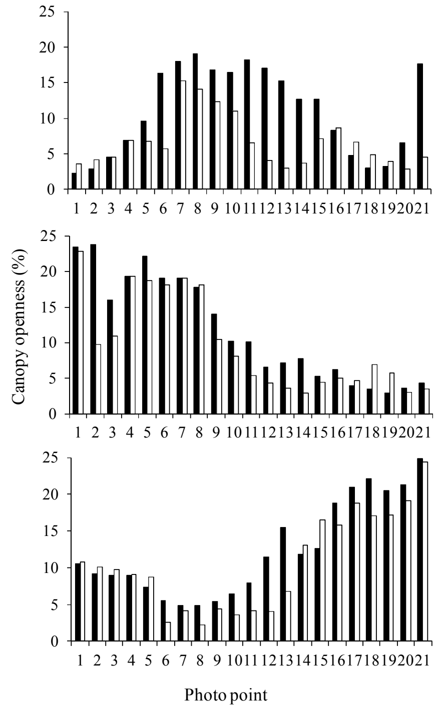

Fig. 7 Change in CO for 1 year in the three strip cutting lines. Filled bars and blank bars indicate the CO measured in 2011 and 2012, respectively. The CO was measured at 5-m intervals along the strip cutting line

In the 20 × 100-m line transect along the strip cutting line, 510 seedlings were recruited 1 year after logging. The species were mainly of the genus *Macaranga*. A comparison between CO change and seedling recruitment suggested the effect of seedling recruitment on the light conditions. At photo points where many seedlings were recruited, a large CO reduction was found (Fig. 8).

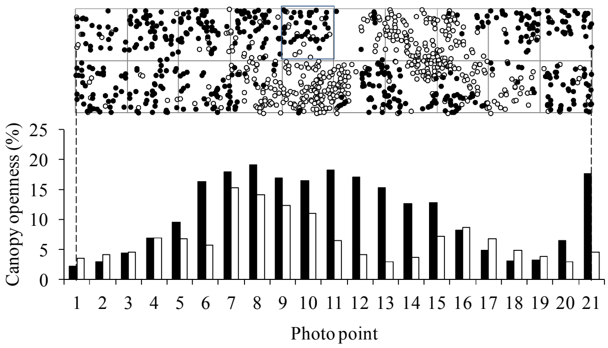

Fig. 8 Seedling establishment in the transect along the strip cutting line (above) and CO change along the line (below). Filled points and bars indicate trees and CO measured in 2011, respectively. Blank points and bars indicate recruitment and CO in 2012, respectively

IV.Discussion

In site PF, intact forest stands, mean CO value was quite low. It is explained by the presence of high multilayer canopies [21]. In contrast, despite using the RIL method, logging activities induced a significant impact on light conditions. Logging changed the light conditions at the forest floor dramatically. However, from a comparison between the mean CO at sites S and SL, no significant difference was observed in the mean CO. These results suggest that neither strip cutting nor the treatment caused significant effects on light conditions.

Based on the stationary measurements, a significant reduction in CO occurred 1 year after logging. From the frequency distribution of change in CO, photo points where a higher CO was originally measured decreased significantly. Canopy closure occurred in areas of previously large CO.

In the comparison of CO change under each disturbance element, the CO reduction was found regardless of the element, i.e., skid trail, logging gap, or strip cutting line. However, even considering the same disturbance elements, a difference was detected in the CO reduction between sites S and SL. The trees at the gap edge responded to the light condition changes according to their biological characteristics [22], and closure after logging seemed to depend on the abundance of surrounding trees.

In addition, from the correlation between canopy closure and recruitment in the strip cutting line, seedling recruitment also appeared to affect light condition changes. Photography was conducted at a 1.2m height, while seedlings responded quickly to light conditions and grew to exceed 1.2m in height. Seedlings covered the camera and affected light conditions to the forest floor. For planted trees, the initial light conditions, and the following changes in the same, are important for survival and growth. Additionally, competition will occur between invasive pioneers and the planted seedlings. Therefore to evaluate the efficiency of strip cutting as a treatment that benefits planted trees, continued monitoring is important.

Acknowledgment

This study was supported by Strategic Funds for the Promotion of Science and Technology of Japan Science and Technology Agency (project title; Creation of a Paradigm for the Sustainable Use of Tropical Rainforest with Intensive Forest Management and Advanced Utilization of Forest Resources) and JSPS KAKENHI Grant Number 22251004 and Grant-in-Aid for JSPS Fellows, 252464.

This study would not have been possible without the support and cooperation of PT. Sari Bumi Kusuma and PT. Wana Subur Lestari.

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