The Indonesian Journal of Geography, Vol.32, No.79-80
June 2000 – December 2000, pp. 1 - 12

THE EFFECTS OF LOGGING ON CANOPY STRUCTURE AND THE PHYSICAL ENVIRONMENT OF A LOWLAND DIPTEROCARP FOREST OF CENTRAL KALIMANTAN

by
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ABSTRACT

The main effect of logging is to create an artificial disturbance regime resulting in canopy gaps and disturbance to soil, seedlings and the forest understory. The effects of logging on the physical environment of a lowland dipterocarp forest in central Kalimantan are being investigated as part of the Indonesian-UK Tropical Forest Management Programme. A range of approaches are being applied to characterise these impacts. The effects of logging on canopy cover, seedling density and soil disturbance are recorded using a "quick assessment" technique to produce low resolution maps of the plots before and following logging. More detailed information about changes in canopy structure is determined using image analysis of hemispherical canopy photographs.

Canopy structure influences most physical processes of importance in the forest ecosystem. The most obvious effect is to increase the amount of radiation penetrating the canopy to the forest floor. The change in the radiation balance of the forest affects many biological and physical processes, notably seedling regeneration and the sub canopy microclimate. The light environment, soil temperature and rainfall interception are used as examples to show the effects of logging on the forest system using data collected from an area of recently logged forest adjacent to currently unlogged permanent sample plots.

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INTRODUCTION.

The forest canopy can be considered to be the entire above ground plant community (Whitmore, 1984). Mature tropical forest canopies are spatially complex with patterns influenced by processes of regeneration, topography and soils (Brokaw, 1985; Raich & Khoon, 1990; Bossel & Krieger, 1991; Bariteau, 1992). The forest microclimate is influenced by the presence of the canopy and is characterised by a reduction in light levels, air temperature and increased humidity (Ashton, 1992; Brown, 1993).

The physical environment within a forest is significantly altered by logging activities. Logging systems create artificial canopy gaps with a variety of sizes, shapes and orientations that depend on the method and intensity of logging. The structure of the forest following selective logging is characterised by a complex mosaic of disturbance and forest types (Cannon *et al.* 1994). The creation of canopy gaps influences forest regeneration with a number of recent studies emphasising the importance of gap size (Brokaw, 1985; Stewart *et al.* 1991; Chandrashekara & Ramakrishnan, 1993; Osunkoya *et al.* 1993).

The purpose of this paper is to describe the changes in the physical environment following logging of a lowland dipterocarp forest in Central Kalimantan, Indonesia. The work has concentrated on defining changes in canopy structure following logging and secondary effects on the sub-canopy light environment, temperature and rainfall interception. The results that are reported form part of a preliminary study of the Indonesia-UK Tropical Forest Management Programme (ITFMP) funded by the British Overseas Development Administration and the Indonesian Ministry of Forestry.

Canopy structure.

The canopy of a tropical rainforest is characterised by structural complexity in three dimensions. The vertical layering or stratification of within the canopy reflects the position of different life forms (Whitmore, 1984). Horizontal spatial pattern is determined by the mix of species within any level and is influenced by topography and soil characteristics. The location of individual trees is determined by natural processes of regeneration including the formation of canopy gaps. The spatial complexity of a rainforest canopy is greatly increased after selective logging such as the Indonesian system for selective logging and tending (TPTI). The forest is then characterised by a mosaic of disturbance. These range from areas of relatively undisturbed forest under closed canopy, through areas with partial canopy on the margin of canopy gaps and finally large canopy gaps or open areas (Cannon *et al.* 1994). There are many methods that have been used to describe the structure of forest canopys. Mapping techniques can be used to represent the forest in two or three dimensions (Whitmore, 1984). Alternative approaches attempt to describe the structure of the forest canopy in terms of structural descriptors such as amount of leaf area per unit ground area or leaf area index (LAI) (Norman & Campbell, 1989). Most studies of tropical forests have used indirect methods such as hemispherical photography (Rich, 1990) to describe canopy structure. The height and complexity of most rainforests make more direct measurements impractical for most studies.

Sub-canopy light environment.

The sub-canopy light environment is strongly influenced by canopy cover and structure (Raich, 1989; Turton & Duff, 1992). The amount of light reaching the forest floor has been estimated using arrays of light sensors (Denslow *et al.* 1990; Mcdonald & Norton, 1992; Rich *et al.* 1993) or indirect methods based on analysis of hemispherical canopy photographs (Anderson, 1964; Chazdon & Field, 1987; Becker *et al.* 1989; Rich *et al.* 1993; Whitmore *et al.* 1993).

Forest Energy Balance

The energy balance of the forest is altered because of increased penetration of radiation into the lower levels of the canopy and to the forest floor. This in turn affects other aspects of the physical environment including air and soil temperature, humidity and the water balance or hydrology of the forest. Logging activity also results in soil disturbance and damage to trees remaining in the stand. The magnitude of these effects on the physical environment will depend on the system of logging and will be influenced by site characteristics such as slope, aspect and soil characteristics.

Rainfall interception.

Rainfall interception by a forested area is a function of canopy structure and density. It represents the proportion of gross rainfall that is captured by the canopy and evaporates and hence does not reach the forest floor. In practice rainfall interception is measured indirectly as the difference between gross rainfall falling on the vegetation canopy, and net rainfall that reaches the ground as throughfall and stemflow (Lloyd *et al.* 1988). Rainfall interception can also be estimated from models based on the energy balance of the forest (Gash *et al.* 1995). In the current study these approaches are being compared and this paper presents preliminary data describing the reduction in net throughfall as a function of canopy cover.

METHODS

Study location

The research forest is located in Central Kalimantan (Long. 1° 18' S, Lat. 112° 23' E) in the headwaters of the Sampit river approximately 180 km NNW of the town of Sampit. The research area consists of 600 ha of lowland dipterocarp forest in an area of hilly terrain towards the North of a logging concession managed by PT Kayu Mas International. The site is typical of lowland Dipterocarp forest in the region.

The research forest is being used in an intensive investigation of ecological aspects of the Indonesian selective cutting and tending system (TPTI) that is a modification of the Malaysian selective management system (Appanah & Weinland, 1990). Fifteen permanent sample plots have been established and nine will be logged by the middle of 1996 according to specifications based on diameter limits representing modifications of the TPTI specifications. The current studies have been conducted in unlogged plots in the main research forest and in a recently logged area adjacent to the research forest that was logged in 1994 according to TPTI.

Canopy cover

Maps of canopy cover were produced using a rapid assessment technique based on a 5*5m grid imposed over each 1 ha plot. A visual estimate of canopy cover was recorded at each grid position using a subjective scoring with three classes of canopy cover. These were, full canopy, partial canopy or no canopy (canopy gap). These data were combined to make a simple map of canopy cover that was subsequently used to define sampling locations for other measurements in the plots. Similar maps were produced for soil disturbance and population density of dipterocarp seedlings but are not reproduced here.

Hemispherical Photography

Hemispherical photography was used to obtained estimates of canopy cover and light levels for locations in the unlogged and logged plots. A hemispherical photograph was taken 1.2 m above the forest floor plot during overcast conditions using an eight mm hemispherical lens (Nikkor, Japan) mounted on manual camera body (Nikon FM2 and MF16 databack, Japan). Photographs were taken on 200 ISO colour slide film (Kodachrome, Kodak, USA) at exposure levels set using an electronic spot light meter (Spot Meter F, Minolta Japan) sighting through a gap in the canopy. The exposure settings were defined with 3 f-stops below meter reading taken as the ideal exposure and bracketed one f-stop either side of this (2 f-stops and 4 f-stops below meter reading).

Grey-scale images were digitised directly from film at a resolution of 40 pixels per millimetre (1024 dots per inch) using a slide scanner (Model 35T, Microtek, USA) connected to an IBM compatible PC, giving a final image diameter of 1000 pixels. Images were analysed to give estimates of diffuse and direct site factors, and leaf area index using customised software running within a commercial image processing and analysis system (Optimas, Version 5.0, Optimas Co., Washington) These methods were based on standard procedures (Norman & Campbell, 1989; Rich, 1990; Whitmore *et al.* 1993) and the detail will be described elsewhere).

Site factors (Rich *et al.* 1993) were calculated assuming a standard overcast sky (diffuse site factor), with solar tracks calculated on a daily basis and sampled at 5 minute intervals (direct site factor). A global site factor (GSF) was calculated as:

$$\mathrm{GSF} = 0.7\ \mathrm{DirSF} + 0.3\ \mathrm{DifSF} \qquad (1)$$

where DirSF and DifSF are the direct and diffuse site factors, representing estimates the proportion of direct and diffuse radiation received on a horizontal surface at the site of the photograph relative to that which would be received under a completely open sky.

Light measurements

Photosynthetically active photon flux density (PPFD) was measured by quantum sensors attached to wooden stakes 1.2 m above forest floor. The 21 sensors (SKP215 Quantum sensors, Skye Instruments Ltd., UK) were connected to a datalogger (CR10 datalogger, AM416 multiplexor, CSM1 card storage module, Campbell Scientific, UK) and calibrated against a single LI-COR quantum sensor (LI-190SA, LI-COR Instruments, Nebraska, USA) before measurements began. Instantaneous fluxes were recorded at 1 minute intervals, and half hour and daily averages were calculated. Measurements were made for 70 days in the unlogged area, beginning in March 1994, and subsequently for 70 days in the logged area, beginning in June 1994. For the logged area the choice of location for direct PAR measurement was stratified by canopy cover classes with seven sensors allocated to each cover class.

Soil Temperature Measurements

Soil temperature was measured at a depth of 2 cm using thermistor soil temperature probes. These were constructed using epoxy coated thermistor chip (100K6A1, Betatherm, Hampshire, UK) sealed inside 5 mm diameter stainless steel tube. The sensors were connected to a datalogger (Delta T Devices, Cambridge, UK) programmed to record soil temperatures every 5 minutes and save the average every 30 minutes.

Rainfall Interception

Total gross rainfall was measured by a tipping bucket rain gauge (ARG-100, Campbell Scientific, UK) located first in a large open site and then at the top of a 65 m tall tower above the forest canopy. Data were recorded on a data logger (CR10, Campbell Scientific, UK) and processed to give values of total rainfall per rain event. In the unlogged plot throughfall was measured in a 100 x 40 m plot with five parallel transects of 100 m. Each transect contained sampling positions at 1-m interval giving a potential total of 505 locations. Fifty throughfall gauges were located at random within this grid with ten gauges assigned to each transect. Eight gauges were constructed from a 18.3 cm diameter plastic funnel mounted above a five litre plastic container. These gauges were randomly relocated within the grid following each rainfall event. Two tipping bucket rain gauges (ARG-100, Campbell Scientific, UK) connected to a CR10 datalogger were assigned to fixed positions within each row of the grid. The measurement of throughfall from plastic containers was carried out after one rainfall event, while throughfall measurement by tipping bucket raingauges was collected from data logger at two weekly intervals using a portable computer. This experimental design should have resulted in a percentage error in mean throughfall of less than 5 % (Lloyd *et al.* 1988).

In logged plot a simple stratified sampling technique was utilised based on the map of canopy cover. The distribution of throughfall gauges was based upon the proportion of each crown coverage in the plot. The gauges were allocated with 19 gauges in open space 19 gauges in areas of partial canopy cover and 17 gauges under closed canopy. Within these three strata of canopy cover, the forty 5 litre containers were randomly relocated after every rainfall event.

RESULTS AND DISCUSSION

Canopy cover and structure.

A grid map of canopy cover is shown in fig. 1 for a 1 hectare logged plot. The white areas represent canopy gaps with light which grade through a region of partial canopy cover into regions with closed canopy. This map emphasis that there are is mosaic of canopy disturbance following selective logging (Cannon *et al.* 1994) and this will create a range of environmental conditions (Ashton, 1992; Brown, 1993).

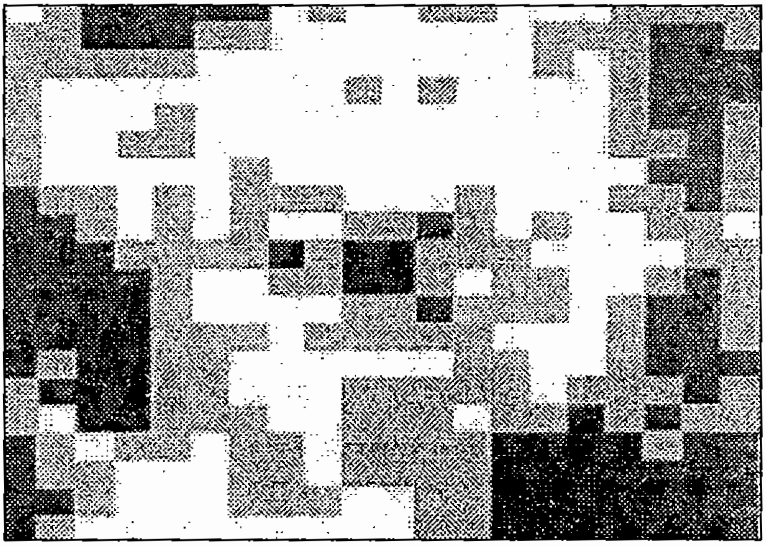

Figure 1. Grid map of canopy cover following logging. The map represents 1 hectare of logged forest mapped using a 5*5m grid. Canopy cover was assessed on a three point scale from closed canopy (black), partial canopy (grey) and canopy gap (white).

The map of canopy cover was used to set sampling locations for measurements of canopy structure, sub-canopy light environment and rainfall interception. Hemispherical photographs were recorded for locations within the closed canopy and canopy gap strata. These photographs were subjected to digital image analysis to obtain estimates of total leaf area index, direct and diffuse site factors (Table 1).

Table 1. Estimates of canopy cover and subcanopy light conditions. Leaf area index (LAI), direct site factor (Direct S.F.) and diffuse site factor (Diffuse S.F.) were determined from image analysis of hemispherical photographs. The average daily photosynthetically active photon flux density was measured by an array of quantum sensors

Canopy Cover	LAI ($m\,m^{-2}$)	Direct S.F.	Diffuse S.F.	PPFD (mol day^{-1})
Open	1.98	0.37	0.27	4.51
Closed	4.97	0.04	0.01	0.23

The leaf area index or leaf area per unit ground area is almost 2.5 time greater under closed canopy compared to the centre of a canopy gap. As a result more light penetrates to the forest floor as is illustrated by the differences in the direct and diffuse site factors and average daily PPFD. An example comparing instantaneous PPFD values for the canopy gap and closed canopy is shown in fig. 2 for one day in August 1994. This figure illustrates the importance of short periods of high light intensity or sunflecks (Chazdon, 1988; Canham *et al.* 1990; Rich *et al.* 1993) for both locations. The importance of sunflecks for the growth understorey plants is well documented (Chazdon, 1988).

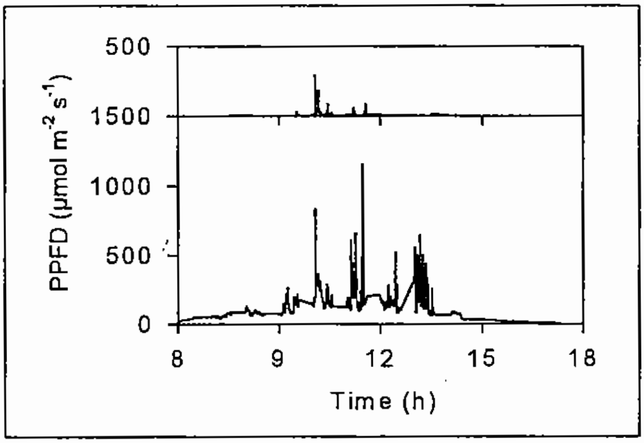

Figure 2. The daily pattern of PPFD recorded by quantum sensors at a height of 1.2 m above the forest floor. (a) Closed canopy site. (b) Canopy gap site. Data were collected on 4 August, 1994 with a logging interval of 1 minute.

Soil temperature

Soil temperatures beneath closed canopy and the canopy gap are shown in figure 3. The difference in energy balance between the sites is clearly shown by the larger diurnal variation in soil temperature under the canopy gap.

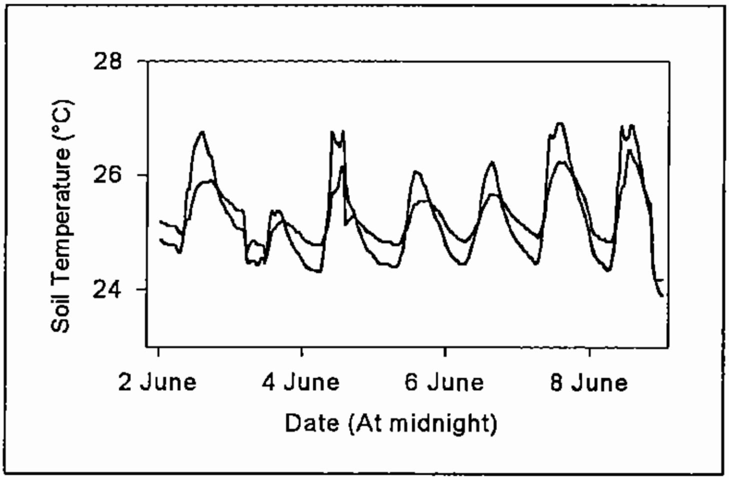

Figure 3. The daily timecourse of soil surface temperature under closed canopy (grey line) and a canopy gap (black line). Data were recorded over an eight day period in June 1994.

Rainfall interception

Preliminary analyses of canopy rainfall interception are shown for different classes on canopy cover in figures 4 and 5. These figures show net throughfall as a function of gross rainfall above the canopy. The slope of this relationship gives an indication of the rainfall interception by the canopy. Net throughfall in the unlogged forest is 92 % of gross rainfall meaning that 6 % is lost by stemflow and canopy interception. Preliminary estimates of stemflow for this site suggest that stemflow does not exceed 1 % of gross rainfall. In the logged plot throughfall is clearly a function of canopy cover. The slope of the regression for the canopy gap and partial canopy sites (disturbed margin) do not significantly differ from one indicating that rainfall interception is negligible. It is noteworthy that the slope for the closed canopy is 0.83, considerably lower than that observed for closed canopy in the unlogged plot. It is impossible to say from these data if this represents variation between sites or is a function of edge effects in the logged forest.

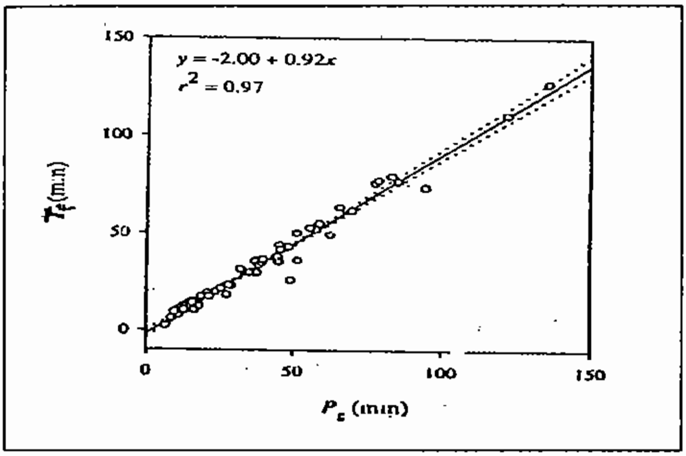

Figure 4. Throughfall (T_f) as a function of gross rainfall (P_g) measured underclosed canopy in unlogged forest. The broken lines are 95% confidence limits for variances.

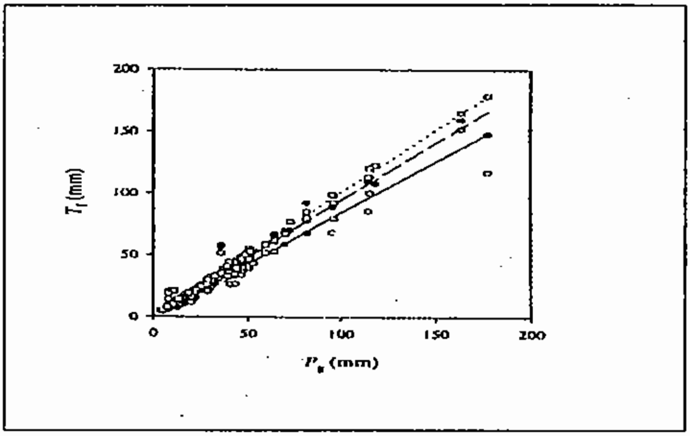

Figure 5. Throughfall (T_f) as a function of gross rainfall (P_g) measured in logged forest. Data were collected for three classes of canopy cover (☐ = canopy gap, • = partial canopy, O = closed canopy). The regression equations are: $T_f = 0.04 + 1.01\ P_g$, $r^2 = 0.99$ (canopy gap); $T_f = 1.77 + 0.93\ P_g$, $r^2 = 0.98$ (partial canopy); $T_f = 1.39 + 0.83\ P_g$, $r^2 = 0.95$ (closed canopy).

The estimate of between 5 and 10 % for rainfall interception obtained indirectly in this study for closed canopy locations is in good agreement with results obtained by similar studies at other sites (Lloyd & Marques, 1988; Sinun *et al.* 1992). The contrast between the results obtained from the three canopy classes in the logged plot illustrates the importance of stratified sampling based on canopy cover.

CONCLUSIONS

The reduction of canopy cover following logging has important effects on the physical environment of tropical forests. The is increased penetration of solar radiation during the day. The increase in light flux observed under canopy gaps is very important in influencing processes of regeneration (Brokaw, 1985; Bossel & Krieger, 1991; Brown, 1993; Chandrashekara & Ramakrishnan, 1993). The change in the energy balance of the forest in gaps following logging leads to increased temperatures and decreased relative humidity in line with other studies elsewhere (Ashton, 1992; Brown, 1993). The effects of changes in canopy structure will affect other physical processes in the forest ecosystem. In the current paper this was illustrated with measurements of rainfall interception, but it should be stressed that this approach could be extended to all aspects of forest hydrology.

These observations stress that there are major effects of canopy cover and structure on the physical environment of forests. Changes in the radiation environment will influence the ecology of the site, particularly processes such as regeneration and stand regrowth. Secondary effects such as soil temperature may be equally important in some situations such as the loss of mycorrhizae in large canopy gaps (Smits, 1983; Alexander *et al.* 1991).

The magnitude of changes in the physical environment will depend on the level of disturbance following logging. For this reason we can state that forest management practice will influence the physical environment and ecological processes in logged forest. Using a suitable mixture of experimental measurements and modelling it should therefore be possible to define an optimal logging regime that promotes long-term sustainable management of tropical forests.

ACKNOWLEDGEMENTS

The data presented here were partly from Wisnu Rusmantoro and Mike Clearwater of the University of Edinburgh. The authors are pleased to acknowledge this support.

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