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LOGGING DAMAGE
IN
TROPICAL HIGH FOREST

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LOGGING DAMAGE
IN
TROPICAL HIGH FOREST

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This report is one of a series of Project Reports prepared during the course of the UNDP/FAO Forest Development Project. The conclusions and recommendations given in the reports are those considered appropriate at the time of preparation. They may be modified in the light of further knowledge gained at subsequent stages of the Project.

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ABSTRACT

Extensive damage to the residual stand does occur in Tropical High Forest during harvesting of the initial crop. The extent of damage is influenced both by the intensity of logging and the degree of skill directed to the planning and execution of the various operations involved.

The aspects of logging technique which contribute to damage are discussed and results are presented from two studies carried out in an area of Mixed Dipterocarp Hill Forest in Sarawak.

The first comprised an experimental logging trial designed to compare the efficiency of the current logging practice with that of an operation planned and executed to predetermined technical standards directed to minimizing damage and reducing overall logging costs. In the planned operation overall damage was halved, skidding efficiency increased by 36% and the directional felling practiced did not increase cost above that encountered in current felling practice.

The second study derives from the analysis of data involving three harvesting intensities of 10 m$^3$/ha, 32 m$^3$/ha and 55 m$^3$/ha. The area occupied by skidtrail and landings was virtually the same for the three study areas, but temporary open space increased from 5% to 30% through the range of harvesting intensities. Under current logging practices, some 60 trees/hectare of desirable species are destroyed in logging 55 m$^3$/ha compared with a loss estimated at 25 trees in the most lightly logged area.

The need to improve the standard of planning and execution of logging operations in the Mixed Dipterocarp Hill Forest is stressed, not only from the viewpoint of reducing the loss of actual and potential raw material but in order to ensure the perpetuation of the forest as a viable entity.
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1. INTRODUCTION

Research concerning the Mixed Dipterocarp Hill Forest (MDF) and its potential as a renewable natural resource has been carried out in Sarawak since 1969. The results of this work have demonstrated that if the selectively logged forest is treated immediately after logging so that sound stems of desirable species are released from competition, the felling cycle can be reduced, the harvestable volume for the next cut being not less than that of the first cut.

The possibility of perpetuating the forest with resultant good harvests depends largely on the existence of immature stems sufficient in quantity and quality to provide good quality timber for subsequent crops. However, during logging operations, some damage to the residual stand is inevitable. This damage, which varies with the intensity of logging, can be reduced substantially by careful planning and supervision of the whole harvesting operation. This was demonstrated very clearly during an experimental logging operation in Sarawak in Mixed Dipterocarp Hill Forest.

2. IMPORTANT CAUSES OF LOGGING DAMAGE

2.1 FELLING

Felling is an operation which can cause extensive damage to the forest during logging, especially if it is carried out with little supervision and without direction except as to minimum diameter, species to be felled and log quality required.

Damage to the forest is particularly severe when large trees with wide spreading crowns are felled in the direction of neighbouring trees which then break and fall against successive stems. In this way quite extensive areas of forest are completely destroyed and the log of the tree felled initially may also be damaged. This type of damage can be particularly severe in forests characterized by an abundance of vines and woody climbers.

2.2 EXTRACTION

Extraction also results in substantial damage to the residual stand. Heavy crawler tractors are so powerful that almost no effort is required to push through a stand of small trees and, with little more effort, quite big trees can easily be uprooted. This power enables the operator to take his machine almost anywhere in the forest provided the terrain is not steep. If the operation develops without planning and adequate supervision, even low intensity selective logging can damage the forest to an extent which severely inhibits the development of the next crop.
2.3 ROADBUILDING

Roads represent an area of the forest which is taken out of production either permanently or temporarily. Main roads are used normally during one felling cycle and the area they occupy can be considered as taken out of production permanently. The area occupied by secondary roads, which are used for a few years and feeder roads which are used during one year only, is taken out of production only temporarily, but regeneration develops very slowly on their hard compacted carriageways. The area occupied by roads in a normal logging operation in tropical high forest is some $40 \text{ m}^2/\text{ha}$ for main roads and $400 \text{ m}^2/\text{ha}$ for secondary and feeder roads. This represents only $4\%$ of the total area being logged.

In the course of road construction trees along the edges of the roadway are exposed to damage from both road clearing and earth moving operations. Such damage can be very serious, particularly on steep sideslopes when earth and broken trees may slide down hill a long way. In addition, the felling of trees which shade the road on each side of the carriageway may cause the same type of damage to the stand as described in section 2.1 above.

3. THE INFLUENCE OF LOGGING TECHNIQUE ON LOGGING EFFICIENCY AND LOGGING DAMAGE

3.1 INTRODUCTION

Damage to the residual stand in a tropical high forest can never be completely avoided. A big tree must make a hole in the stand when it is felled and tractors need trails when extracting logs. However, the damage must be kept to a minimum, if the forest is to be retained as a perpetual supplier of merchantable trees.

The extent of logging damage depends to a large extent on the logging technique employed. An appropriate technique will minimize damage to the residual stand, but ensure an efficient operation. A system of directional felling, in combination with the proper planning of skidtrails prior to logging, will result in higher production and less damage to the residual stand than in conventional logging as practiced in Sarawak. The difference was demonstrated during 1979 in Mixed Dipterocarp Hill Forest (MDF). Two blocks, each of 300 acres were allocated to the Forestry Development Project for the establishment of a logging trail. One block was set aside for experimental logging and the other area, referred to as the control block, was logged conventionally. Both blocks were the subject of a series of studies both during and following logging. The combined area was designated as Research Plot (RP) 111. The study area was typical of the MDF at lower altitudes in Sarawak, with rather broken topography and generally short but not too steep slopes often intersected with steeper terrain.
3.2 THE LOGGING TECHNIQUES

3.2.1 The Experimental Block

All operations in the experimental block were carefully planned and efficiently supervised. It is worth noting, however, that both the feller and tractor operator were not at all accustomed to this logging technique which was new to them. They were trained only as the work progressed.

Great emphasis was placed on the felling direction of all trees. Each tree was felled in such direction as to cause as little damage as possible to the surrounding trees, while at the same time facilitating the skidding operation and ensuring maximum log recovery. Emphasis was placed also on the planning and preparation of skidtrails to ensure efficient skidding as well as felling. Skidtrails were of two types, being either main trails or secondary trails.

Both main skidtrails and landings were planned on a map prepared from topographic survey and drawn to a scale of 1:3,000 with contour intervals of 5 metres. An enumeration of the stand was made during the course of the survey and a map prepared to show concentrations of commercial trees. Reconnaissance and alignment of the main trails were carried out with the map in hand, using clinometer and compass and they were all located and opened before any felling was permitted.

The main trails were located as close as possible to the denser stands of timber and, to the extent that the terrain permitted, parallel to each other and at right angles to the road, and following a favourable grade to the landing. Trails were planned as straight as possible, avoiding steep adverse grades and sharp curves which slow down speed and increase skidding damage. Adverse grades were limited to 15% and favourable grades over 30% were avoided.

The distance between main skidtrails was determined by the concentrations of timber, the average number of trees/hectare, and the felling method to be adopted. Where trees were fairly evenly distributed the distance between trails was 100-150 metres. Topography also influenced the location and spacing of skidtrails. In places the terrain was so difficult that no systematic trail pattern could be planned and the trails were located where the terrain permitted.

Secondary skidtrails were short, not exceeding 50 metres in length and located as skidding progressed and wherever needed to reach logs which could not be skidded directly from the main trail. They were located so that as many logs as possible could be taken out on the same trail and, where terrain permitted, parallel to each other and at an angle of 45° - 90° from the main trail. Junctions with the main trail were open curves, to facilitate entry of the tractor to the main trail and to minimize breakage and damage to logs hauled and to standing trees.
To make skidding as simple and efficient as possible, all trees were felled in a herringbone pattern in relation to the main-trails. Where possible, trees were felled towards the trails at an angle of $30^\circ - 45^\circ$ to the skidding direction; the skidder then reaches the log without having to penetrate the crown or go around it, thus minimising damage to the remaining stand. Care was taken not to fell the tree so that the crown covered the skidtrails. The optimum position for the felled tree is when its upper bole falls across the trail with the crown on the other side.

When lean or other factors did not permit felling towards the trail, the tree was felled in the opposite direction. Felling at right angles to skidding was always avoided because in that position skidding is more difficult, especially for long logs, and will result in excessive damage to the remaining stand as the log twists around in an arc before moving in the direction of the skidtrail.

Wherever possible, trees were not felled directly down steep slopes in order to avoid damage to both the log and the stand. This can result from the felled tree sliding downhill and destroying other trees in its path.

If logs can be grouped during felling, a load is made up much easier and faster, with resultant increased production. This was done frequently, and at times it was possible to lay one crown over the other, thus reducing still further damage to the remaining stand.

The full skidding capacity of the machine was utilised by employing chokers and hauling two or more logs in the one load. With this system a chokerman is employed, his job being to attach a choker to each log, to locate the best approach path to each log and to mark the secondary skidtrails. If required, the chokerman also indicates at what point the tractor should leave the main trail and how best to approach each log. The tractor operator follows the markings or indications given by the chokerman until he reaches the logs and turns the machine into a position to begin skidding. The chokerman runs out the winch cable and hooks it to each choker which has has previously set on the log to be skidded in that load.

### 3.2.2 The Control Block

In this block the felling and skidding were both carried out in accordance with the practice which has been traditional in most Sarawak logging operations. There was little planning of the harvesting operation and it was carried out without technical supervision. The tractor operator and the feller were together solely responsible for the operations of felling and skidding to the loading ramp. The system followed is detailed below.
After arriving with his tractor and mobile living quarters at the logging block, the tractor operator makes a brief reconnaissance to decide where to locate his landing. Once this decision is made, felling begins at the landing and proceeds into the logging block. After clearing the landing, the tractor follows behind the feller proceeding from log to log and skidding them one at a time, extending his skidtrail as he follows the felling operation.

Trees are felled in the direction convenient to the feller and are thus scattered at random over the block. Extending as they do from log to log, skidtrails are usually long, steep and winding, sometimes completing a full circle; curves are often very sharp. As a result the skidding tends to be slow and damage both to logs and the remaining stand is excessive. The tractor operator has one assistant known as the hookman, who works with the machine at all times, proceeding back and forth between forest and landing. Thus, the tractor operator must spend some time searching for each log or lose valuable tractor time while his assistant searches and locates it. Frequently however, the tractor driver moves aimlessly around with his tractor until he eventually locates a log, destroying many trees in the remaining stand during his search.

Once a log is located the tractor operator turns his machine and the hookman then attaches the cable. If this operation proves difficult from the initial position, the tractor may be moved again to a better position or the log pushed or lifted to a better position with the dozer blade. During all this activity many more trees of the remaining stand may be destroyed or damaged. At times the tractor may even completely circumnavigate the whole log, this resulting in even greater destruction. Should the log lie at a sharp angle to the intended skidding direction, the log must be turned after the hook is attached and even more trees broken or damaged.

At times, but infrequently under this traditional system, two logs are skidded together. Chokers are not used and the main cable must be pulled around the ends of both logs. This is achieved by pushing the logs together with the tractor. This results in further damage to the remaining stand.

3.3 COMPARATIVE EFFICIENCY OF THE TWO SYSTEMS

In order to compare the efficiency of production, time studies of felling and skidding were carried out in both logging blocks. The equipment used in each block consisted of the normal chainsaws and crawler tractors of 140 HP, with winch but without logging arch or fair lead. Chokers were used in the block logged experimentally.
Skidding costs (direct manpower and machine costs) were recorded as follows:

1. **Experimental Block**
   - Planning of main skidtrails (office & field) $\text{M}0.06/\text{m}^3$
   - Opening of main skidtrails prior to felling $\text{M}0.06/\text{m}^3$
   - Supervision of operations $\text{M}0.12/\text{m}^3$
   - Actual skidding $\text{M}4.32/\text{m}^3$
   - Total Cost $\text{M}4.56/\text{m}^3$

2. **Control (Traditional Skidding)**
   - Total Cost $\text{M}5.94/\text{m}^3$

Hence, the reduction in cost for a planned and efficient operation was in the order of 23%. If the cost of making the topographic maps is included ($\text{M}0.23/\text{m}^3$), the total cost for the experimental skidding becomes $\text{M}4.79/\text{m}^3$, and the reduction in cost is approximately 19%. However, the topographic map is primarily an aid for road planning and the bulk of this cost should be a charge to road construction, rather than to skidding.

In terms of machine efficiency the difference between the experimental and the traditional logging can be assessed as 36%, i.e. 20.0 m$^3$/hour skidded as against 14.7 m$^3$/hour over an average distance of 290 m which was the same in each case.

It is of interest to note that the cost of felling was the same for each operation. Thus the directional felling was achieved without any increase in cost.

### 3.4 LOGGING DAMAGE

So as to make a comparison of a logging damage, an area of 2.4 hectares was studied in each block some six months after logging was concluded. All living and dead stems were enumerated, including cut stumps, broken stems and fallen stems. The presence or absence of less severe damage on living trees was recorded and an estimate made of the extent of bare soil (skidtrails, landings, etc) and temporary open space (gaps caused by felling).

Logging damage was calculated for all species of current or potential commercial value. All fallen trees, living broken stems and living standing trees with logging injury were assumed to be damage by logging. Thus a few trees were not recorded, such as trees uprooted and totally destroyed by logging and trees which, although left standing died within the period of six months between the conclusion of logging and the recording of logging damage.
A summary of the data recorded is presented in the three tables below. Table 1 summaries the number of trees/hectare and their basal area by DBH08 classes and the total volume of all trees logged. Table 2 shows the areas of open space in two categories and Table 3 details damage in terms of trees uprooted, broken stems and those with lesser injury, undamaged and the total number of stems.

<table>
<thead>
<tr>
<th>DBH Class (cms)</th>
<th>Control Block</th>
<th></th>
<th>Experimental Block</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trees No./ha</td>
<td>B.A. m²/ha</td>
<td>Volume m³/ha</td>
<td>Trees No./ha</td>
</tr>
<tr>
<td>40-60</td>
<td>2.92</td>
<td>0.74</td>
<td></td>
<td>3.75</td>
</tr>
<tr>
<td>60-80</td>
<td>5.83</td>
<td>2.26</td>
<td></td>
<td>4.17</td>
</tr>
<tr>
<td>80-100</td>
<td>2.92</td>
<td>2.13</td>
<td></td>
<td>3.33</td>
</tr>
<tr>
<td>100+</td>
<td>1.67</td>
<td>2.09</td>
<td></td>
<td>3.33</td>
</tr>
<tr>
<td>Total</td>
<td>13.34</td>
<td>7.22</td>
<td>53</td>
<td>14.58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Logging Technique</th>
<th>Temporary Open Space</th>
<th>Bare Soil (Landings &amp; Skidtrails)</th>
<th>Total Open Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>17.1</td>
<td>10.4</td>
<td>27.5</td>
</tr>
<tr>
<td>Traditional</td>
<td>30.4</td>
<td>10.4</td>
<td>40.8</td>
</tr>
</tbody>
</table>
Table 3: Logging Damage in RP 111

<table>
<thead>
<tr>
<th>Block</th>
<th>DBH Class (cms)</th>
<th>Uprooted Trees No./ha</th>
<th>Broken Trees No./ha</th>
<th>Complete Trees Injured No./ha</th>
<th>Undamaged No./ha</th>
<th>Total Trees No./ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-40</td>
<td>12.08</td>
<td>11.25</td>
<td>25.42</td>
<td>67.08</td>
<td>115.83</td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>1.25</td>
<td>2.08</td>
<td>2.08</td>
<td>9.17</td>
<td>14.58</td>
</tr>
<tr>
<td></td>
<td>60+</td>
<td>-</td>
<td>0.42</td>
<td>2.50</td>
<td>4.17</td>
<td>7.08</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>13.33</td>
<td>13.75</td>
<td>30.00</td>
<td>80.42</td>
<td>137.50</td>
</tr>
<tr>
<td>Control</td>
<td>10-40</td>
<td>25.00</td>
<td>21.25</td>
<td>21.67</td>
<td>62.50</td>
<td>130.42</td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>0.83</td>
<td>1.25</td>
<td>3.33</td>
<td>6.25</td>
<td>11.67</td>
</tr>
<tr>
<td></td>
<td>60+</td>
<td>-</td>
<td>-</td>
<td>2.92</td>
<td>4.58</td>
<td>7.50</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>25.83</td>
<td>22.50</td>
<td>27.92</td>
<td>73.33</td>
<td>149.59</td>
</tr>
</tbody>
</table>

Tables 1 and 2 show that although logging intensity was much the same in each block, the damage done in the experimental block was substantially lower than that resulting from traditional logging. Some 17.1% of the area of the experimental block was classified as temporary open space as against 30.4% in the control block, even though the area occupied by skidtrails and landings was the same at 10.4%. Table 3 shows that some 13 trees/hectare of commercial species were uprooted in the experimental block and an additional 14 were broken. Corresponding numbers for the control block are almost twice as high, but minor damage was slightly more common in the experimental block.

Research data from another experiment indicates that approximately 35% of the trees with minor damage will not recover. Applying this figure to the data of RP 111 suggest that another 11 trees/hectare will be lost due to injury in the control block, against 12 trees/hectare in the experimental block. Thus, the total number of trees of commercial species lost due to logging approximate 40/hectare in the experimental block, compared with 60/hectare in the control block.
3.5 LOSS OF HARVESTED MATERIAL

A more efficient logging technique is expected to reduce not only costs and damage to the residual stand, but also any loss arising from damage to logs harvested. An attempt was made to estimate this type of loss.

In the control block (traditional harvesting), 3.3 trees/hectare were felled but were left in the forest. A quarter of these (0.8 per hectare) showed extensive rot and a further 1.3 tree/ha were hollow and split during the felling operation. Logs from these trees were of such poor quality that their removal from the forest was uneconomic. The remaining 1.3 log per hectare were not damaged and would have contributed a further 11.5 m³/hectare of sound timber to the harvest. In the experimental block only 1.25 felled trees per hectare were either left in the forest or only partly extracted. None of these trees was split, but two logs (0.8 stem/hectare) were free of serious defects and would have contributed 5.5 m³/hectare to the harvest.

4. THE INFLUENCE OF LOGGING INTENSITY ON LOGGING DAMAGE

4.1 THE EXPERIMENTAL BASIS

The relationship between logging intensity and damage was studied, using data from two study plots in the same general locality. One of these plots (RP 102) is a silvicultural experiment established in 1977 shortly after logging had been completed. Logging in this plot was very selective due mainly to the poor market conditions then existing. Two units, each of 4 hectares were used in the analysis, unit 10 because of its extremely low logging intensity and unit 33 because of its relatively high logging intensity. The enumeration of this experiment was done in the same manner as that for RP 111, except that fallen trees were not recorded.

In addition to RP 102 data, that from the control block of RP 111 (enumerated area 2.4 hectares) was taken as representative of the most intensive harvesting, logged according to traditional practice as was the area of RP 102. The area covered by RP 111 was harvested during the very buoyant market conditions of 1979, hence logging was much more intensive than in areas logged during 1977.
4.2 LOGGING INTENSITY

The numbers of trees felled and their basal areas are summarised below, for each of the areas detailed in section 4.1 above.

Table 4: Logging Intensity

<table>
<thead>
<tr>
<th>DBH Class (cms)</th>
<th>RP 102/10</th>
<th>RP 102/33</th>
<th>RP 111/Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trees No./ha</td>
<td>B.A. m²/ha</td>
<td>Trees No./ha</td>
</tr>
<tr>
<td>40-60</td>
<td>-</td>
<td>-</td>
<td>0.50</td>
</tr>
<tr>
<td>60-80</td>
<td>1.00</td>
<td>0.38</td>
<td>2.00</td>
</tr>
<tr>
<td>80-100</td>
<td>0.75</td>
<td>0.45</td>
<td>2.00</td>
</tr>
<tr>
<td>100+</td>
<td>0.25</td>
<td>0.37</td>
<td>1.75</td>
</tr>
<tr>
<td>Total</td>
<td>2.00</td>
<td>1.20</td>
<td>6.25</td>
</tr>
</tbody>
</table>

The range of logging intensity is considerable, varying from approximately 2 trees/hectare for unit 10 of RP 102 (estimated volume 10 m³/hectare) to over 13 trees/hectare (estimated volume 53 m³/hectare) for the control block of RP 111. Although the logging intensity in this block is high according to present standards, trees of commercial quality and size were left standing. Hence, even more trees may be taken out in future operations.

4.3 THE EXTENT OF TEMPORARY OPEN SPACE AND BARE SOIL

Table 5 presents a summary of this data for the three areas considered.

Table 5: Temporary Open Space and Bare Soil in Recently Logged Forest

<table>
<thead>
<tr>
<th>Research Plot/Unit</th>
<th>Basal Area Felled (m²/ha)</th>
<th>Percentage of Total Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bare Soil</td>
<td>Temp. Open Space</td>
</tr>
<tr>
<td>RP 102/10</td>
<td>1.2</td>
<td>7.9%</td>
</tr>
<tr>
<td>RP 102/33</td>
<td>3.9</td>
<td>13.3%</td>
</tr>
<tr>
<td>RP 111/Control</td>
<td>7.2</td>
<td>10.4%</td>
</tr>
</tbody>
</table>
It can be seen that, in spite of the differences in logging intensity, about one-tenth of the total area consisted of skidtrails and landings, recorded as areas of bare soil. However, temporary open space increases dramatically as logging becomes more intensive. After very light logging, only 5% of the area was temporary open space, but when logging reached timber boom intensity, the figure was 30%. This means that the area remaining under standing forest following intensive logging does not exceed 60%. This figure is important from the viewpoint of the perpetuation of the forest and its capacity to provide a subsequent crop of adequate volume within a period of 25 to 30 years.

4.4 THE NUMBERS OF BROKEN, FALLEN AND INJURED TREES

Table 6 presents a summary of the number of uprooted, broken, injured and undamaged stems of species presently or potentially commercial recorded following the logging of the areas described earlier.

<table>
<thead>
<tr>
<th>Research Plot/Unit</th>
<th>DBH Class (cms)</th>
<th>Uprooted Trees No./ha</th>
<th>Broken Trees No./ha</th>
<th>Complete Trees</th>
<th>Total Trees No./ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Injured No./ha</td>
<td>Undamaged No./ha</td>
</tr>
<tr>
<td>RP 102/10</td>
<td>10-40</td>
<td>n.a.</td>
<td>5.25</td>
<td>8.00</td>
<td>85.50</td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>n.a.</td>
<td>0.50</td>
<td>1.25</td>
<td>12.00</td>
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<tr>
<td></td>
<td>60+</td>
<td>n.a.</td>
<td>0.75</td>
<td>0.25</td>
<td>8.00</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>n.a.</td>
<td>6.50</td>
<td>9.50</td>
<td>105.50</td>
</tr>
<tr>
<td>RP 102/33</td>
<td>10-40</td>
<td>n.a.</td>
<td>6.75</td>
<td>5.25</td>
<td>80.00</td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>n.a.</td>
<td>0.50</td>
<td>2.50</td>
<td>8.75</td>
</tr>
<tr>
<td></td>
<td>60+</td>
<td>n.a.</td>
<td>0.75</td>
<td>0.50</td>
<td>7.50</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>n.a.</td>
<td>8.00</td>
<td>8.25</td>
<td>96.25</td>
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<tr>
<td>RP 111/Control</td>
<td>10-40</td>
<td>25.00</td>
<td>21.25</td>
<td>21.27</td>
<td>62.50</td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>0.83</td>
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<td></td>
<td>60+</td>
<td>-</td>
<td>-</td>
<td>2.92</td>
<td>4.58</td>
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<tr>
<td></td>
<td>Total</td>
<td>25.83</td>
<td>22.50</td>
<td>27.92</td>
<td>73.33</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>149.59</td>
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</table>
The high incidence of temporary open space and bare soil following the heavier traditional logging in RP 111 (Table 6) suggests that many trees were either uprooted or damaged during harvesting. As seen in Table 6, this was indeed the case; some 26 trees/ha of commercial species were uprooted and a further 22 stems were broken. In other words, approximately one-third of the potentially commercial stems remaining by the logging operation. The data presented suggests that the damage resulting from less intensive logging is much less, only 6 - 8% stems being broken during the logging of RP 102.

Approximately 100 stems/ha of commercial species were neither harvested nor destroyed in the control block of RP 111, but 28 of these suffered injury. On the basis of 65% recovery from injury (see section 3.4), another 11 trees/ha will die within a few years. Again, it can be seen from Table 6 that the incidence of this type of damage is much less in areas less intensively logged. In summary it can be said that the total loss due to traditional logging will approximate 60 trees/ha of commercial species in intensively logged areas like RP 111, representing some 40% of the growing stock left after logging. The damage in RP 102 and other lightly logged areas is considerably less; an estimate of 20-30 trees/ha appears reasonable. As has been demonstrated earlier in section 3.4, the loss resulting from intensive logging such as that of RP 111 is reduced to 40 trees/ha if the harvesting is well planned and supervised and directional felling is practised.

5. DISCUSSION

The data presented in this paper indicate that damage to the remaining stand as a result of the style of logging practised traditionally in Sarawak MDF is extensive, even when the harvest is selective and light. Future harvests from the virgin MDF are expected to approach the 50 m$^3$/ha cut from the area of RP 111; that intensity of traditional logging destroys, at least temporarily, 40% of the residual forest, and kills almost half of the young growing stock. Under these circumstances, silvicultural treatment of the forest is difficult to justify and it will prove impossible to achieve the desired 25 to 30-year cutting cycle.

Results from the logging study of RP 111 show that the well planned and supervised harvesting operation employing directional felling does far less damage to the residual stand than traditional logging, reducing the number of trees lost by 33% and the area of forest temporarily destroyed by over 40%. Thus, even at a logging intensity of 50 m$^3$/ha, the damage although by no means negligible, is lessened to the extent that silvicultural treatment is warranted and the undamaged growing stock adequate to provide a further crop within a 30-year time span.
It is of interest that results from work done in Sabah show a trend similar to that outlined above. This is seen in Table 7 below, where figure quoted by Nicholson (1958) are compared to those from the control block of RP 111. More recent studies by Fox (1968) and Liew (1973) show even greater damage at higher logging intensities.

Table 7: Comparison of Damage in Traditional Logging in Sabah and Sarawak

<table>
<thead>
<tr>
<th>Location</th>
<th>Trees Felled</th>
<th>Percentage of Commercial Trees</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No./ha</td>
<td>m²/ha</td>
<td>Fallen/Broken</td>
</tr>
<tr>
<td>Sabah</td>
<td>11.6</td>
<td>6.8</td>
<td>29.8%</td>
</tr>
<tr>
<td>Sarawak</td>
<td>13.3</td>
<td>7.2</td>
<td>32.3%</td>
</tr>
</tbody>
</table>

There is some indications that the area occupied by skidtrails and landings (temporary open space) increases with increasing intensity of logging, from about 8% when extracting 2 trees/ha (RP 102 unit 10) to some 13% when extracting 6 trees/ha (RP 102, unit 33). Nicholson (1958) quotes 14% when logging 12 trees/ha in Sabah, using a similar technique to that of the traditional logging in Sarawak. There is some indication that the area of skidtrails can be reduced with better logging technique; although the area of temporary open space over the limited sampled areas of RP 111 (2 x 2.4 ha) was equal for each block at 10.4%, the skidtrail density over the whole experimental block was 136 m/ha against 174 m/ha for the control block, some 22% less for the planned operation.

An inspection of the study area illustrates clearly the importance of directional felling as a factor in minimising damage to the residual stand. This effect was achieved without any increase in felling cost, something of a surprise to the fellers, but possible if viewed logically. Although larger trees cannot be felled directly against their lean and those hollow at the butt are impossible to fell other than in the direct line of their lean, most sound trees can be felled towards their leaning side within an arc of almost 180°, i.e. almost 90° either side of the centre of the lean direction. Thus, the feller has considerable freedom of choice whereby he can fell to avoid damage, both to the log for which he is paid end to the residual stand, and this he can do without any special aid or effort.

The use of chokers resulted in less damage and increased machine efficiency, due to fewer skidding trips and no time lost in searching for logs. The nett result was larger loads handled in less time, and tractor time is expensive.
The planning, location and opening of the main skidtrails prior to felling made it possible to achieve an optimum trail pattern and density, with trails of higher quality which were straighter and better aligned to the topography. Winding, steep trails inevitably result in substantial damage to the residual stand, many stems being broken or destroyed when large, long logs negotiate steep slopes and bends. Organization and supervision is simple and efficient in any operation which is well planned from the start, the work is much less dangerous, fewer trees are left unfelled and fewer logs are lost after being felled.

It is instructive to consider alternative logging practices which might conceivably do less damage to the residual forest than those reviewed above.

For felling there is no alternative to the chainsaw. However, forests characterised by the occurrence of woody climbers, felling damage will be reduced by cutting these vines prior to felling, thus reducing the number of stems pulled down or broken by the tree being felled. Fox (1968) and Liew (1973) indicate a substantial reduction of fallen and broken stems by employing this technique in Sabah. The crawler tractor is viewed as a machine which is very damaging to the forest. However, the use of wheeled skidders or FMC steel-tracked high speed skidders does not preclude the use of the crawler, which must be used to open skidtrails and, in difficult terrain, to break out the logs to the skidders which work only on the main trails.

An alternative system which is used for extraction in tropical forests is that of cable logging. However, cable systems available today which are less harmful to the remaining stand are very expensive, and in view of the relatively small volumes removed per unit area in many tropical forests, the use of this equipment is rarely economical. The standard high lead system which may at times be economical, will cause even more damage than the more conventional tractor logging.

For road construction the bulldozer will always be used for certain work. Although excavators are being used increasingly and effectively for construction even in steep terrain, they are employed in combination with bulldozers. An excavator moves and places earth faster and with more care than can a bulldozer.

In conclusions it can be said that the most promising way to improve the traditional logging in the MDF of Sarawak is by employing a system of directional felling in combination with a well planned skidding operation making full use of chokers. However, it is essential to appreciate that no improved logging technique, no efficiency, and no reduced logging damage can be achieved in any logging operation unless is it properly supervised by trained operatives.
ACKNOWLEDGEMENTS

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REFERENCES


