Lessons learned from the implementation of reduced-impact logging in hilly terrain in Sabah, Malaysia

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SUMMARY

Between 1992 and 1997, about 2400 ha of old growth dipterocarp forest in southeastern Sabah was logged according to reduced-impact logging (RIL) guidelines as part of a pilot carbon offset project. Harvest planning, vine cutting, directional felling, and skidding restrictions contributed to a reduction in stand damage from 50% to 28% of the original stems; damage to soil was reduced from 13% to 9% of total area in RIL relative to conventional logging areas. Residual stands in RIL areas had greater vertical structure and better stocking of commercial timber species than stands in conventionally logged areas, with positive gains for conservation of biodiversity and sustainability of timber production. Steep terrain and the lack of predictable dry periods were constraints on the ground-based skidding system, and resulted in large volumes of timber being inaccessible, and in production delays caused by wet weather. Introduction of an aerial yarding system in this region would allow a greater proportion of the areas to be harvested in an environmentally acceptable way.

Keywords: logging damage, soil disturbance, steep slopes, stocking, wet weather shutdowns.

INTRODUCTION

Concern over unnecessarily destructive timber harvesting practices and rising levels of anthropogenic greenhouse gas emissions stimulated the development of a reduced-impact logging (RIL) project in Sabah in 1992. The aim of the project was to reduce damage to soils and the residual forest by one half, relative to local conventional harvesting operations. By reducing incidental tree mortality, less biomass would be lost from the forest, carbon emissions from decaying debris would be reduced, and the capacity of the forest to sequester carbon would be maintained. The initial project (1400 ha) was funded by a US-based power company as a pilot carbon offset project, where the potential implications of damage reductions for greenhouse gas emissions could be explored (for discussion of the rationale for the carbon offset see Putz and Pinard 1993, Pinard and Putz 1996, Pinard and Cropper (in press). The project was extended to an additional 980 ha in 1996, funded by a consortium of power companies also interested in the offset potential of RIL.

The key environmental problem that the project was intended to address was excessive damage to soils and advanced regeneration during conventional harvesting operations. On average when old growth dipterocarp forests in Sabah are logged, 8-15 trees are extracted per ha, representing 50-150 m^3 of timber. As many as 40-70% of the residual trees are damaged (Fox 1968, Sabah Forestry Department 1989) and 15-40% of the area traversed by bulldozers (Chai 1975, Jusoff 1991). Little pre-harvest planning is done, available topographic maps are unreliable, and lack of co-ordination between chainsaw and bulldozer operators results in inefficient and damaging operations (Pinard *et al.* 1995). Current practices in Sabah are not sustainable because the volumes of timber extracted, the area logged each year, and damage to advanced regeneration are all too high (Sabah Forestry Department 1989). Although a new silvicultural system is needed (Udarbe *et al.* 1994), this project's focus was on harvesting only.

PROJECT AREAS

The project is based in old growth dipterocarp forest in three forest reserves in southeastern Sabah[1]. The forests are diverse in tree species (Fox 1978, Newbery *et al.* 1992), and heavily stocked with commercial trees; average basal area ranges between 25 to 33 m^2 ha^{-1} (trees $\geq$10 cm dbh), about 68% of this is in commercial species (Pinard and Putz 1996). Mean canopy height is 45 m and emergent trees reach 70 m. The terrain consists of a series of short (200-300 m long), steep ridges. On average, only 22% of the project areas had

[1] The project areas include three parcels: 450 ha in Ulu Segama, 5° 0' N, 117° 30' E, 150 - 750m asl), 950 ha in Kalabakan (4° 25' N, 117°29' E, 150 - 900 m asl), 980 ha in Gunung Rara (5° 0' , 117° 30' E, 150 -750 m asl).

slopes less than 20 degrees; 46% had slopes 20-34 degrees and 29% had slopes greater than or equal to 35 degrees (Table 1). Underlying geological substrates and soils are variable (Nussbaum 1995). Rainfall is aseasonal, with mean annual rainfall at the three forest reserves ranging from 2700-3100 mm yr^{-1} (estimated from Walsh 1996).

TABLE 1 *Percent of study areas in slope classes. The two logging treatments were reduced-impact logging (RIL) and conventional logging (CL)*

Reserve	Ulu Segama		Kalabakan		Gunung Rara
Slope	RIL	CL	RIL	CL	RIL
<10°	9%	1%	2%	21%	5%
10-19°	20%	13%	15%	30%	15%
20-29°	28%	38%	32%	34%	26%
30-34°	16%	22%	20%	10%	22%
35-39°	10%	22%	14%	2%	15%
≥ 40°	16%	6%	16%	3%	17%

Notes: estimates are based on slope measurements taken in permanent plots (1600-3200 m^2) distributed in a stratified random manner in study areas. Sample sizes were as follows: Ulu Segama, RIL N=138, CL N=120; Kalabakan, RIL N=127, CL N=125; Gunung Rara, RIL N=86.

The project is managed by Rakyat Berjaya, the forest products subsidiary of Innoprise Corporation Sdn Bhd (ICSB), the commercial arm of the Sabah Foundation (Yayasan Sabah). The project sites are within the Sabah Foundation timber concession. The state forestry department issues annual cutting licences and harvesting operations are largely subcontracted out to private companies. All pre- and post-harvesting silvicultural operations are conducted by Rakyat Berjaya. The reserves do not have human populations living within their borders.

The conventional timber harvesting system used in Sabah since the mid-1960s is based on a minimum harvesting diameter of 60 cm dbh, and bulldozers are used to make skidding trails and to extract logs (Sabah Forestry Department 1989). The management system is a modified uniform system with 60 year cutting cycles, but is currently under review and revision (Kleine and Heuveldop 1993). Typically, the only silvicultural activities implemented, aside from harvesting, are a pre-harvest inventory (2.5%) and post-harvest regeneration sampling. Although other silvi-cultural treatments (*e.g.* pre- and post-harvest climber cutting, girdling of non-commercial stems) were included as prescriptions in the original system, these treatments were dropped in the mid-1970s because high levels of damage associated with harvest meant that only a small proportion of the residual forest warranted treatment (Chai and Udarbe 1977). Generally at the time of harvest, some advanced regeneration is present. Dipterocarp seedling densities tend to be variable both spatially and temporally.

RIL areas were harvested by crews trained in reduced impact logging techniques. The Ulu Segama parcel was harvested in 1993-1994, the Kalabakan parcel was harvested in 1995-1996, and the Gunung Rara parcel was harvested in 1997-1998.

The project maintains a rigorous monitoring programme for measuring impacts on residual trees and soils. The monitoring programme used in the first project site (Ulu Segama) was designed to address several objectives: 1) to provide reliable estimates of damage to soils and residual trees in RIL and conventional logging (CL) areas as measures of project effectiveness; 2) to provide data to document changes in standing stocks of carbon in RIL and CL areas over time; and, 3) to provide growth and yield data. The programmes used in the second (Kalabakan) and third (Gunung Rara) sites were designed to address the first objective only. The rangers also keep detailed records of all operations to facilitate re-entry for the next cut and to provide information on contractor compliance with the guidelines.

DESIGN OF MONITORING PROGRAMME

The basic design of the monitoring programme involves pre- and post-harvest measurements of stand conditions in project areas (*i.e.* to be logged according to RIL guidelines) and in adjacent areas to be logged using conventional practices. Prior to logging in each of the first two project sites, permanent plots were established at a 10% intensity in four logging units randomly selected from RIL and four from CL areas. Units in the RIL and CL areas were paired according to topography and logging schedule to reduce variability in logging impacts due to soil moisture and slope. Plots were located in a stratified random manner. In the third project site, sampling intensity was dropped to 2.5% (3.2% in RIL, 1.6% in CL) in order to reduce costs. At this site, no logging unit divisions were used and plots were located in a stratified random way throughout the 980 ha project area and the adjacent 1000 ha CL area[2].

Trees in the plots were tagged, mapped, and diameters measured at breast height (at 1.3 m or above buttresses, hereafter, dbh). For commercial trees, species or species group was recorded. Any existing damage to trees was recorded. Plots were reassessed for damage 5-30 days post-harvest. Damage was recorded by type (*e.g.* stem, crown, bark, root) and intensity (5 point scale). In the first project site, plots were again resurveyed 10-12 months post-harvest to measure tree mortality and again three years post-harvest to measure growth, recruitment, and mortality. Summary pre- and post-harvest data are presented in Table 2.

In each of the first and second project sites, soil disturbance was mapped and measured at 100% intensity in the eight logging units (four RIL, four CL). In the third project site, soil disturbance was estimated from sampling along transects located in a stratified random way. A summary of results is presented in Table 3.

[2] At the time of publication, the data from the CL area are unavailable.

TABLE 2 *Pre-logging conditions and timber extraction data from 3 reduced impact logging (RIL) and 2 conventional logging (CL) area in three forest reserves*

Reserve	Ulu Segama		Kalabakan		Gunung Rara
	RIL	CL	RIL	CL	RIL
Pre-logging (no. ha^{-1}) harvestable trees	23.3 (4.4)	21.7 (2.3)	19.5 (4.5)	18.0 (2.1)	16.6 (7.8)
Pre-logging basal area trees ≥10 cm dbh (m^2 ha^{-1})	27.4 (3.4)	27.5 (4.3)	26.4 (4.0)	23.2 (3.8)	26.5 (0.7)
Area unlogged (% of total)	44% (19)	0% (-)	43% (15)	1% (3)	47%
Trees (no. ha^{-1}) extracted from net area logged	8.8 (3.6)	13.6 (2.7)	8.4 (2.1)	11.2 (1.1)	5.3 (8.6)
Volume (m^3 ha^{-1}) extracted from net area logged	103 (54)	152 (23)	81 (20)	111 (7)	50 (49)
Volume (m^3 ha^{-1}) extracted from entire block	60 (30)	152 (23)	48 (20)	111 (7)	27 (9)

Notes: means presented with standard deviations noted parenthetically. Estimates from Ulu Segama and Kalabakan are based on mean values of four logging units (50-70 ha), subsampled with 15-35 plots per unit. The estimates from Gunung Rara are based on 87 plots distributed in a stratified random way throughout the entire 980 ha. Harvestable trees are trees of commercial species, >60 cm dbh. Estimates expressed per net area logged are based on a sub-sample of the plots, excluding plots located in areas that were not logged. More detail on methodology can be found in Pinard and Putz (1996).

TABLE 3 *Soil disturbance as a proportion of total area in the study areas. The two logging treatments were reduced-impact logging (RIL) and conventional logging (CL)*

Reserve	Ulu Segama		Kalabakan		Gunung Rara
	RIL	CL	RIL	CL	RIL
Area with disturbed soil	6.8% (2.6)	16.6% (2.3)	9.5% (5.1)	10.2% (1.5)	9.3% (8.3)
Roads and landings	3.3% (2.5)	4.7% (0.8)	0.4% (0.6)	Not available	1.2% (1.6)
Skidding trails (total)	3.5% (2.1)	11.9% (2.7)	9.1% (4.7)	8.0% (1.1)	6.9% (6.2)

Notes: values presented are mean percentage of total area with standard deviation noted parenthetically. Sample size in Gunung Rara was 21 transects of variable length, totalling 3.2 km. Sample size in RIL Kalabakan was 8-10 transects of 100m in each of three logging units.

DEVELOPING RIL GUIDELINES

The motivation for the project initially came from the Sabah Foundation's interest in carbon offsets for gaining funds for improving forest management. As the pilot project was being developed, an initial set of guidelines was drafted based on best management practices recommended in Indonesia, Malaysia and Australia. The guidelines have been reviewed biannually and revised to make them more appropriate to local conditions. The rangers working in the field have been instrumental in the improvement of the guidelines. Throughout the project, they have worked to increase the efficiency and effectiveness of harvesting and developed a record-keeping system to document progress. (For more details on implementation of the project and development of the harvesting guidelines see Pinard *et al.* 1995). The logging crews and forest rangers working in the first experimental area were trained by foresters from the Queensland Forest Service and by expert fellers from Sweden. Subsequent crews and rangers involved in the project have been trained by personnel within the project and ICSB.

To increase the project's transparency and credibility, an independent committee was set up to assess compliance with the guidelines. The Environmental Audit Committee has three members, one appointed by the timber concessionaire, one by the power company and one joint appointment. The committee meets about every 6 months to review progress and to conduct an audit. Any changes in the harvesting guidelines must be approved by the committee. The committee reviews the results from the monitoring programme and the rangers' records but conducts its own field assessment to determine compliance. The involvement of the committee provides a mechanism for discussing and reviewing issues related to implementation of the guidelines.

Local research efforts have been directed at measuring environmental and ecological impacts (*e.g.* Pinard and Putz 1996, Howlett 1998, Pinard *et al.* in press), costs and benefits (Tay 1999), and implications for carbon storage (Pinard and Cropper 2000), hydrology (R. Walsh and W. Sinun unpubl.), silviculture (M. Pinard unpubl.) and biodiversity (Davis in review).

KEY FEATURES OF RIL PROCEDURES

The guidelines include specifications for pre-harvest planning, vine cutting, felling, skidding and post-harvest site closure. A 100% stock map (1:5,000 scale) is prepared which shows all harvestable trees, stream and road buffer zones, and sensitive areas that are to be excluded from logging. Furthermore, during stock mapping rangers note topographic features that are not apparent on the 1:50,000 maps used for harvest planning. Map improvements have often proved useful when laying out roads and major skid trails, but the cost savings in construction and maintenance are difficult to estimate. Stock map preparation is costly (about 40% of additional direct operational costs, Tay 1999) but the rangers involved in the project have repeatedly argued for their utility, particularly in increasing their familiarity with the forest and for their application for future harvests.

Vine cutting is conducted at least one year prior to harvest and vines ≥2 cm dbh are cut in areas to be harvested. Efforts are made to avoid cutting *Ficus*, other root climbers, and other species of known importance to wildlife but this requires training in identification that has sometimes not been forthcoming. If, prior to vine cutting, efforts were made to identify areas deemed unloggable due to slope, proximity to streams, or other reasons, potential negative impacts of vine cutting could be reduced, as could costs. However, to date rangers have been reluctant to identify these areas prior to the initiation of vine cutting.

Bulldozers are required to stay on marked primary and secondary skidding trails and operators are encouraged to use their winches to bring the logs to the bulldozer. Use of the bulldozer blade on skidding trails is prohibited on slopes <20 degrees; on slopes ≥20 degrees, the blade may be used in skidding trail construction only. Skidding trail width is restricted to a 4.5 m working surface (5 m if slope ≥20 degrees). Skidding is prohibited on slopes ≥35 degrees and although no explicit wet weather restriction is stated in the guidelines, the philosophy of minimising damage restricts the use of heavy machinery when soils are saturated.

Skidding trails are marked on the harvest plan and in the field, with end points clearly indicated. Trees to be felled are marked with an "X" and a 1 m long painted line to mark the direction of intended fall. Potential crop trees (trees ≥15 cm dbh of commercial species) that occur near trees to be felled or skidding trails are marked with a blue ring to increase their visibility.

Closing operations include the removal of temporary stream crossings and installation of drainage structures on roads and skidding trails. The guidelines call for functional draining cross drains on skidding trails on slopes, with a recommended density of cross drains related to slope and fetch.

LESSONS LEARNED

Effectiveness of RIL regimes in reducing damage

At all three project sites, implementation of the guidelines resulted in a substantial reduction in damage relative to conventional practices (Figure 1). Damage to soils was also less in RIL areas relative to CL areas, both in terms of area damaged (Table 3) and degree of disturbance to topsoils (Pinard *et al.* in press). Volumes extracted from the RIL logging units have been, on average, lower than in CL areas[3] (Table 2). The reductions in logging damage recorded in RIL areas, however, cannot be attributed to lower harvesting intensities alone. When the variability associated with extraction levels is removed, stand damage in CL areas substantially exceeds that in RIL areas. Also, the slopes of the lines representing the relationship between basal area extracted and proportion of basal area killed are similar for the two logging methods; the intercept, however, is greater for CL than RIL areas (Figure 2), meaning that for a given

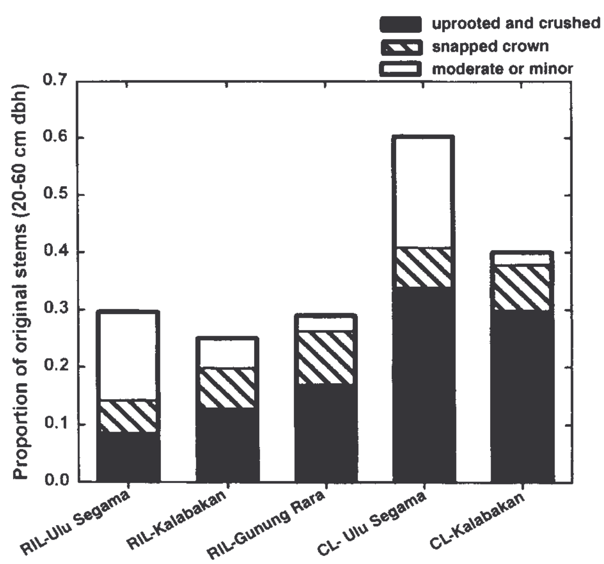

FIGURE 1 *Logging damage in reduced-impact logging (RIL) and conventional logging (CL) areas in Sabah. Bars represent mean values from 4 logging units (50-70 ha), subsampled with 15-35 plots; plots in unlogged areas were not included in the analysis*

[3] Nevertheless, mean volumes extracted from RIL areas, when expressed per net loggable area, are within the range of the concession average of 70 m³ ha⁻¹.

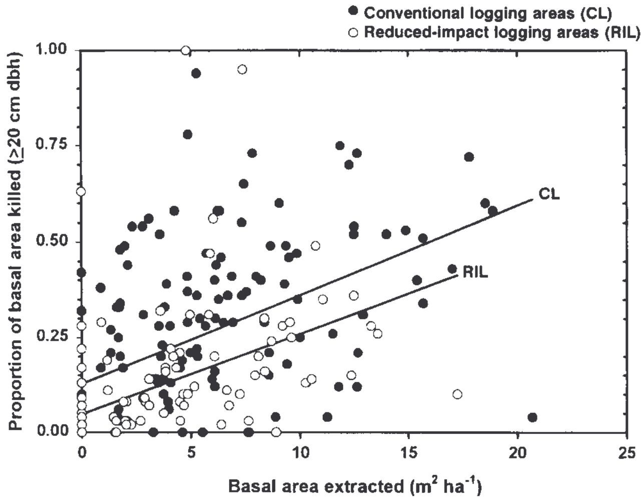

FIGURE 2 *Relationship between basal area extracted and proportion of basal area of residual stand killed during harvest (includes only trees >20 cm dbh). Each point represents a plot; basal area extracted was measured in plots of 3200 m^2, basal area killed was measured in a nested subplot of 800m^2. The plots were distributed in a stratified random way through four units (50-70 ha) for each logging method (data from Kalabakan Forest Reserve)*

extraction level, the proportion of the stand killed was greater in CL than in RIL areas[4].

Costs

Implementation of RIL guidelines in the first project area was associated with additional direct operating costs of \$135 ha^{-1} or \$1.27 m^{-3} (for a full discussion of costs and benefits see Tay 1999). Stock map preparation and vine cutting were the two most costly activities. An additional \$45 ha^{-1} was spent on the monitoring programme, specifically for permanent plot establishment and two post-logging assessments (Tay 1999). Time studies (Tay 1999) documented gains in efficiency in skidding operations in RIL relative to CL areas but tree felling times were slower. The results of the cost-benefit analysis conducted for project area (Tay 1999) were heavily influenced by the reduction in timber revenues associated with inaccessible timber in RIL areas[4].

Monitoring programme

If the monitoring programme developed for the project in Sabah had been intended to monitor contractor compliance with the harvesting guidelines, a different, less intensive programme would probably have sufficed. However, in this case study, the investors in the project, both the electric utility and the timber concessionaire, were interested in determining the value of investments in RIL for carbon offsets. Because reliable estimates of project impacts are essential for validating any claim of an offset, they were willing to invest in a more substantial monitoring programme.

Residual stand conditions and silvicultural implications

Perhaps more important than the degree of damage reduction during harvest is the effect of implementation of RIL guidelines on conditions in residual stands (Figure 3). After logging, RIL areas had more large trees (≥60 cm dbh) than CL areas; this difference in vertical structure may have important implications for biodiversity conservation. RIL areas also had more trees of 10-40 cm dbh than CL areas. It has been suggested that the difference in stocking levels of potential crop trees, combined with higher volume increments, could translate into a reduction of the cutting cycle by 50% (Kleine 1997). However, any proposition to change the cutting cycle should be approached cautiously. More frequent entries: 1) would be associated with an increase in logging damage; 2) may increase the forest's vulnerability to fire by creating more open stand conditions for a larger proportion of any rotation; 3) may have potential negative impacts on fauna, particularly hunted species; and, 4) may result in extraction levels that are unsustainable in the long term.

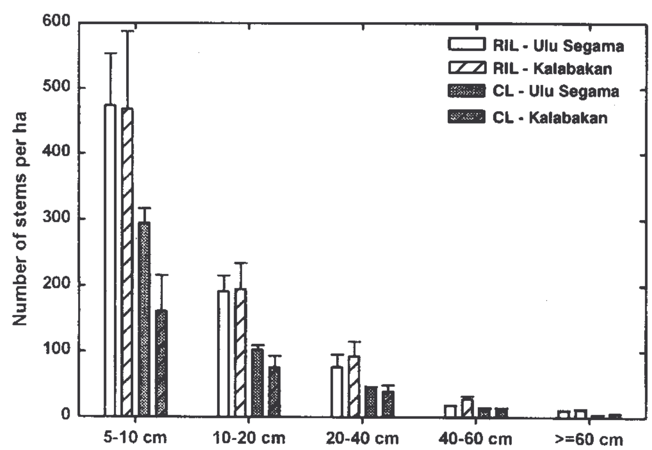

FIGURE 3 *Residual stand structure in areas logged according to reduced-impact logging (RIL) guidelines and areas logged using conventional (CL) methods. Data are from Ulu Segama and Kalabakan Forest Reserves. Mean values for 4 logging units subsampled with 15-37 plots presented. Unlogged portions of RIL areas were not included*

Even when harvesting is conducted in a careful manner, there may be an intensity threshold above which the level of incidental damage is no longer acceptable (Sist *et al.* 1998, Van der Hout 1999). Stand damage was generally within acceptable limits in RIL areas. The exception was where clusters of trees had been felled. Felling clusters resulted in unacceptably large gaps which often became dominated by lianas, climbing bamboo, or pioneer vegetation; the first two

[4] Only a small proportion of the variation in fatal damage was explained by the regressions, however (R^2 = 0.27 for CL, R^2 = 0.4 for RIL).

vegetation types are of particular concern because of the potential for delaying forest recovery. Small modifications to the tree selection rules could reduce this problem. For example, the number of trees to be felled in groups could be restricted, and the likelihood of vine or bamboo invasion in an area could be considered.

Slope considerations for harvesting

The areas of old growth forest that remain within the Sabah Foundation's concession tend to have rugged topography and unstable soils (Table 1). These slopes have been a major constraint for ground-based log extraction. Restrictions against the use of bulldozers on slopes >35 degrees is justifiable on environmental grounds, indeed many best management practices prohibit heavy machinery on slopes >20 degrees. However, because operators working in CL areas were not working with a slope restriction, the restriction on logging on steep slopes was associated with substantial volumes of foregone timber. In the three project areas, about 43-47% was unlogged due to steep slopes or unstable soils. Although the timber can be harvested when the appropriate technology becomes available, this foregone timber represents a high opportunity cost for the concessionaire and logging contractor.

Converting to an aerial based yarding system in steep and rocky areas seems the obvious solution to the problem of inaccessible timber. Apparently viable options include helicopter yarding and skyline operation. Helicopter yarding would require little training of local people as it would be necessary to employ a helicopter yarding company. Currently, the yarding costs are thought to be prohibitive but the use of helicopters in Sarawak suggests that it might be worth investigating costs further. Skyline systems are less costly per cubic metre yarded to the roadside than helicopter yarding and given the Forestry Department's current positive experiences with skyline yarding in Deramakot Forest Reserve, this seems a more feasible option. A combination of bulldozer and skyline yarding may be the most cost-effective. Investment in a new yarding system would be more attractive if there were some assurance that the newly trained contractor (and operators) would remain working with the concessionaire.

Within the project some tests have been made of the effect of relaxing the guidelines to allow the bulldozers access to steep slopes but otherwise follow the existing RIL guidelines (Kalabakan). Trials conducted to date have generally resulted in an unacceptable amount of soil disturbance in areas where skidders operated and on roads, both in terms of degree and extent. Furthermore, the steep skidding trails were difficult to drain and therefore became gullied and unlikely to be reusable.

Wet weather constraints

The lack of seasonality in rainfall meant that work in RIL areas was often delayed; on average there were 18-25 rain days per month. Again, trials with wet weather skidding resulted in deep 'box cuts', trails that could not be drained, increased soil compaction and subsoil disturbance. Use of an aerial yarding system would reduce this problem.

Construction of proper drainage structures on skidding trails was facilitated by requiring use of a small backhoe (or excavator). Functioning cross drains were difficult to construct using bulldozers, partly because of the need to manoeuvre the bulldozer without causing additional damage. In many cases, it was necessary to employ a worker to manually open part of the cross drain to ensure that it would drain. In areas of skidding trails and roads where deep box cuts had formed (mostly due to skidding during wet weather), it was very difficult to install any drainage structures. Water bars or 'bumps' were used to slow water flow but in most cases, the bars were breached within a couple of weeks resulting in severe erosion.

Extending cable winching capacity could also help to reduce problems with soil disturbance and slope restrictions. In general the bulldozers operating in the RIL areas have 32mm winch cables that are about 30 m long. The cable is heavy and difficult to drag distances of more than 10-12 m. Recommended options for increasing winching distance included a change to a lighter cable or the use of a small winch to pull out the main cable. The problem was ultimately solved by employing a second worker to assist in setting the cable. Other improvements on skidding that have been suggested include the use of chokers, an arch, or skidding pans but, to date, none have been adopted by the contractor.

CONCLUSION

Implementation of the RIL guidelines resulted in reductions in stand damage from 50% to 28% of the original stems, and soil damage from 13% to 9% of the total area in RIL relative to CL areas. Timber volumes extracted in RIL areas, when expressed per net area logged, were about 70% of the volumes extracted in CL areas. While buffer zones near streams and sensitive areas are responsible for part of the reduction, the larger part of the reduction is probably due to a tendency of fellers working in RIL areas not to fell trees likely to cause extensive damage.

Post-harvesting stand conditions suggest that the benefits for silviculture and biodiversity conservation are potentially great. Higher densities of large trees in RIL areas provide the vertical structure important for certain species. The higher stocking levels of trees 10-40 cm dbh in RIL areas are expected to result in higher commercial volume increments over the next cutting cycle.

Wet weather shutdowns delayed operations and restrictions against skidding on steep slopes made a proportion of each project area 'unloggable' using the current ground-based system. Introduction of an aerial system, or a hybrid system where bulldozers are used in combination with a skyline system, could help to reduce the opportunity costs associated with minimising logging damage in this region.

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