REDUCED IMPACT LOGGING: A GLOBAL PANACEA? COMPARISON OF TWO LOGGING STUDIES

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The Tropenbos-Guyana and Tropenbos-Cameroon programme

INTRODUCTION

In recent years, several major events have drawn the attention of the public to the importance of forestry and the global environment. Perhaps the most important of these was the United Nations Conference on Environment and Development, which was held in Rio de Janeiro in June 1992. One of the main outcomes of this Conference was the explicit recognition by policy-makers that forests are essential for sustainable economic development and also for the cultural and physical well-being of current and future generations. To ensure that forests are sustained for future generations and to improve the economic and social contributions of forestry, environmentally-sound harvesting techniques that will improve standards of utilisation and reduce environmental impacts should be developed and promoted. Given the current state of knowledge, however, it is not clear whether specific practices will actually achieve the desired outcome: i.e. that the standards of sustainable forest management be met.

Publications on reduced-impact logging or the improvement of codes of practice for sustainable management are on the increase. After Mattson Mårn and Jonkers (1981) in Sabah, Ward and Kanowksi (1985) in Australia, and Hendrison (1990) in Suriname, a whole new generation of researchers have taken up the topic, and all describe its advantages: Crome *et al.* (1992) in Australia; Blate (1997) and Johns *et al.* (1996) in Brazil; Webb (1997) in Costa Rica; van der Hout (1996) in Guyana; Bertault and Sist (1995) in Kalimantan; Pinard and Putz (1996) and Cedergren *et al.* (1994) in Sabah. Some describe the methods and the results obtained more precisely than others (i.e. quantitatively), but the general message is: reduced-impact logging is less destructive than conventional practices and increases utilisation standards. These conclusions suggest that there should be no hesitation among logging companies to start employing this practice or for governments to enforce its implementation. On the contrary, the adoption of the techniques remains an elusive goal. In the Brazilian Amazon, for example, only a few forestry operations have implemented low-impact-logging techniques, despite the legal requirements to do so (Uhl *et al.*, 1996). The question arises: what withholds the implementation of these techniques (see also ter Steege, this seminar).

Two projects concerning the impact of selective logging have more or less been completed at the same time in two different Tropenbos programmes: one in Guyana, the other in Cameroon. While writing their reports, the authors discussed their respective results, explained what they had learned from complementary experiences, and sought support for their impressions and conclusions. For the purpose of this seminar, they have placed their tentative results in the framework of reduced-impact logging for sustainable management. The difference in set-up, and in the scientific and natural environment between the two projects became clear. In this paper, we will focus on the impact of selective logging on the vegetation and how this was attenuated by introducing reduced-impact-logging systems. The impact of these systems on the cost/benefit aspects will not be considered here.

DEFINITIONS

What are ›conventional practice= and ›reduced-impact logging=? Some expressions may need further clarification before we continue. Both logging practices refer to selective logging of commercially viable stems, meaning a limited number of individuals (of a minimum size and stem quality) out of a restricted number of tree species.

Reduced-impact logging (RIL), in our view, comprises new techniques and new concepts of organising and planning timber harvesting, with the primordial objective of damage reduction, and with a proximate goal of improving the efficiency of the operation. ‘New’ in this context means new to the environment and to the society in which these concepts are to be introduced. They are consequently experimental, and hence a topic of research and validation. The adjective ‘reduced’ hints at a comparison with another logging method, obviously the current, conventional practice. So RIL is about new, not yet commercially validated logging techniques that lead to less damage than the conventional methods of logging.

Now, *conventional practice* covers a broad range of methods, varying from ‘*savage*’ forest exploitation (timber mining with hardly any degree of planning at all) to ‘*close-to-best practice*[1]’. Which extreme to chose? Comparing the RIL concept with savage-logging practices does not really put new technological and conceptual developments in their right perspective. The commonly presented RIL package includes many concepts and techniques already present in the close-to-best practices. This means that many of these concepts and techniques have already been validated on a practical scale and have been incorporated in a company’s production strategy.

We consider this clarification and demystification of RIL important when looking at the aspects of disseminating research results. Taking enterprises practising savage logging to the level of close-to-best practice can best be done by demonstrating or imposing techniques that have already been commercially validated by the forestry sector itself. Taking the *avant-garde* enterprises a step further to RIL level can best be done through a comparison between their current standard of practice and the experimental one. To really demonstrate the added value of new concepts and techniques, a comparison of the RIL concept with close-to-best practices would therefore seem a far more useful exercise.

BACKGROUND OF THE TWO PROJECTS

The two Tropenbos programmes differ considerably in set-up. The Guyana programme hooked on to an existing programme of the University of Utrecht. It formally commenced in 1989 and initially involved the Departments of Plant Ecology and Evolutionary Biology, and Physical Geography, the former being represented by the sections Vegetation Ecology, Ecophysiology, and Herbarium. Its focus has been on trees and their environment, with special attention to individual tree species, population dynamics, environmental stress, plant-animal interactions, and biodiversity offset by human-induced disturbances, specially artificial canopy gaps. In its current second phase, this scope has been broadened, notably with ethnobotany and non-timber forest products. The forestry component was inserted in 1992, with a study to assess the impact of logging intensity on logging damage and subsequent growth and yield rates. Reduced-impact logging, following the system developed by Hendrison (1990) in the neighbouring country of Suriname, was treated as an extrinsic variable in the research (i.e. it was included in the experiment as a complete package approach to be compared with conventional practice). The core of the programme was basically ecological in nature, and forestry was dealt with within one project only.

In Cameroon, the Department of Forestry of the Agricultural University of Wageningen started a multi-disciplinary research programme from scratch in 1994. Best represented from the onset were Land-Use Planning, Economy, Social Science, and Logging research. Logging research was rather a separate project in a range of complementary forestry studies. The study focussed largely on the logging itself and aimed at the modification of current logging practices towards reduced- impact logging. No ecological or silvicultural studies had been undertaken at the start of the research. Social science and land-use studies did make tentative results available and could thus be taken into account.

In Guyana, the above factors led to an intrinsic link between logging, silviculture, and ecology, whereas in Cameroon the study tended towards a scrutiny of logging operations and their relationship with the rest of the production chain and the local forest population.

The environmental setting of the two programmes also differed, specially concerning the forest composition and the presence of forest dwellers (Table 1). Forests in Guyana are relatively poor in terms of species (*cf*. Ek, 1997) and log dimensions. Traditionally, logging has targeted mono-dominant patches of exploitable species in the forest, the most important being Greenheart (*Chlorocardium rodiei*, Lauraceae), a timber species. Recently, the set of targeted species has been broadened by an increased demand for peeler species, which is related to an increased interest of mainly South-East Asian timber companies. Logging activities in the study area, although also influenced by an increased marketability of lesser-used species, still aim at Greenheart. Because of the clumping of this species, selective logging in Guyana is disturbing the landscape in a very patchy fashion, and exploitation can reach a level of 20 stems per hectare or $60m^3$/ha (Clarke, 1956; Zagt, 1997). Tree diameters are relatively small, most logs being smaller than 70 cm. The canopy height of Greenheart reaches 30-40 m. Some sought-after species are emergents and attain large diameters, but these usually comprise only a small proportion of the harvest.

In Cameroon, the forests are richer in species; no similar-sized clusters occur, and large individuals are broadly dispersed. Logs are considerably bigger on the average. The concessionaire focuses mainly on Azobé (*Lophira alata*, Ochnaceae) for its sawn timber. Adult individuals of Azobé and most other marketable species are emergent, and therefore cause considerably more damage upon felling than trees belonging to the canopy.

Another important difference in setting is the fact that the concession area in Guyana is virtually uninhabited, whereas sedentary as well as shifting-cultivation dwellers are present in Cameroon. Cameroon is also a prominent tropical timber exporting country while this is not the case for Guyana. The reasons for this difference can be found in the extremely low population density in Guyana, its relatively poor forests, and its geographical position. Because of the latter, Guyana is not located along a major trade route, which increases the transportation cost and results in smaller export profit margins.

The two projects coincide in the choice of their partners: both conduct their research in ›close-to-best practice‹ concessions, owned by foreign companies. The terrain of the two projects also correspond, both being flat to gently rolling.

Table 1 Characterisation of the environmental setting of the two Tropenbos research sites

	Guyana	**Cameroon**
Species diversity	moderate	rich
Exploitable species	in patches	dispersed
Topography (slopes)	<20%	<20%
Diameter range	under 120 cm	sometimes > 200 cm
Average diameter	60 cm	120 cm
Exploitation level (100 ha)	2 trees = 6 m^3/ha	0.5 tree = 6 m^3/ha
Concessionaire	Close-to-best practice	close-to-best practice
Forest dwellers	uninhabited	6 per km^2

HARVESTING PHASES

Four components can be identified in environmentally-sound harvesting practices (Dykstra, 1996):
1) Harvest planning;
2) Implementation and control of harvesting operations;
3) Assessment and communication of results between planners and operators;
4) A competent and properly motivated workforce.

Harvest planning should be a part of overall forest-management planning. The strategic harvest plan describes non-harvest areas, annual operating areas (coupes), the working methods, the main transportation and extraction system, and annual labour requirements. The tactical harvest plan provides the details of operations within the annual coupe. The following aspects are usually recommended for tactical harvest plans:
- Preparation of topographic maps;
- Identification of individual cutting units (blocks);
- Inventory of the trees per cutting block;
- Layout of a detailed transportation and extraction system;
- Scheduling of operations to accommodate the timing of, for example, the rainy season (Dykstra, 1996).

The comparison of the two logging studies focuses on these aspects and on the logging method. We will tackle these aspects not from a tactical viewpoint but from a strategic viewpoint. We will focus on the four harvesting phases most cited in literature: a) inventory, b) pre-felling logging activities, c) felling, and d) skidding.

INVENTORY

In temperate forests, forest inventory for harvesting through sampling is usually sufficient (see e.g. de Vries, 1986), as the volume to be harvested from each hectare is high and it is not necessary to know the location of each individual tree. In mixed tropical forests, the volume harvested per hectare is usually low, and it is now generally considered essential to make a complete inventory of all trees that might be harvestable (100% enumeration) to reduce harvesting and infrastructure cost.

The traditional way of making an inventory in both countries (close-to-best practice situation) is that a cutting block is delimited by cut lines, usually 1 km apart. Between these cut lines, the forest is divided into strips, which are systematically browsed to locate harvestable stems. The position, size, and species are marked on a map, together with topographic details such as slope direction, gullies, and streams (see e.g. Hendrison, 1990). It is also common practice to project this information on a blown-up version of a standard topographic map, scale 1:50,000 (Guyana) or 1: 200,000 (Cameroon). The map that is used for felling and skidding has a scale of 1:2,500 in Guyana and 1: 5,000 in Cameroon.

The tree-stock map assembled in this way may look neat, but contains a high degree of false accuracy. Firstly, the blown-up grid of contour lines is too coarse and does not take into account very local steep slopes and ridges. Secondly, the combination of primitive field equipment (compass and surveyor's rope), dense vegetation, and the strip system lead to considerable deviations from the reality in the forest. A compass misreading of only one degree will lead to an error of more than 17 m on a strip length of 1 km. Larger deviations are not uncommon when working under dense forest conditions. Moreover, the tree's position is represented by a circle, in which species code, tree size, and tag number are pictured, which easily takes up 1 cm on the map = 50 m. Consequently, mapped tree locations and distances between trees show great aberrations.

Surprisingly, the low accuracy of the map generally appeared to pose no problem with the low density of the trees to be felled and skidded in Cameroon. The prospector still had time to locate trees while the feller was busy bucking the previously felled tree, and the logging clerk could lead the way to the next tree when the skidder was on its way to and from the landing. In Guyana, the density of the trees to be felled is often high. In this case, a low accuracy can influence the efficiency of the operation, because trees are being omitted or felled in the wrong sequence.

But what demands does Reduced Impact Logging (RIL) impose on the quality of the current inventory work? One of the major credits ascribed to RIL is the reduction of damage to the residual forest - especially to sub-adult trees of commercial species - by designating skid trails and by directional felling. For this purpose, it is important to know the number and condition of these potential crop trees (PCT), as well as seed trees, and to know where they are. Hence it is often suggested that they should be included in the pre-felling inventory. But it should be realised that the number of trees to be mapped doubles when trees only 10 cm below the cutting limit are taken, and triples when trees 20 cm below the cutting limit are taken. In the case of Guyana, where tree densities can already reach 20 trees per ha, there would be physically no space left on a map with a scale of 1:2,500. In Cameroon, larger map scales were experimented with, but did not improve accuracy. There are also practical reproaches; the daily coupe should be on one manageable map.

It is also suggested that the direction of fall of each tree to be harvested should be marked on the map. Indicating the expected and proposed direction of fall of a tree would require space to such an extent that the map would be fully filled and hence not workable.

CONCLUSION

To accommodate the demands that RIL imposes on forest inventory for harvesting (e.g. inclusion of potential crop trees, mapping of proper alignment of the designated extraction system, and indicating the direction of fall) requires more accurate topographic and tree position information and a better presentation of the inventory data. Within the current inventory technology, the current inaccuracies can only be partially tackled by increasing the scale of the maps and working with smaller inventory blocks. A switch to a completely new technology, GPS/GIS, for instance, may be inevitable.

Table 2 Pre-felling logging activities in two countries

Frequently mentioned activities	**Location**	**Cameroon**	**Guyana**
Planning	in camp	some	some
Climber cutting	in forest	no	no
Marking PCT	in forest	no	no
Marking Seed trees	in forest	no	no
Skid trail alignment	in forest	some	no

PRE-FELLING LOGGING ACTIVITIES

In the current discussions on Reduced Impact Logging, there is a lot of attention for activities that should take place before one proceeds with the actual felling of the trees that were enumerated during the inventory. A whole array of activities is mentioned in literature. It is usually advised to perform them during the inventory, or to base them upon the results of the inventory. The actual state of affairs in Cameroon and Guyana is that none of these activities are employed (Table 2). Their applicability was studied explicitly in Cameroon. In Guyana, three activities were incorporated in the RIL experiment: 1) planning; 2) climber cutting, and 3) pre-felling skid-trail alignment.

Table 3 Constituting elements of harvest plan preparation

Activity	**Current practice**	**Reduced Impact Logging**
Manpower-machine input	present	frequently mentioned
Designation cutting blocks	present	frequently mentioned
Roads and landings	present	frequently mentioned
Designation buffer zones	absent/present	frequently mentioned
Skid rail alignment	absent	frequently mentioned
Tree selection system	absent	rarely mentioned
Seed trees	absent	rarely mentioned
Social trees*	absent/present	rarely mentioned
Exploitation level*	absent	rarely mentioned
Felling patterns*	absent	not mentioned

* = added by the authors

Planning

The preparation of the harvest plan requires a confrontation of the working-method outline - as described in the strategic plan - with the actual results of the inventory. Planning commonly comprises the planning of the monthly production, the machine and personnel input, and the planning of cutting blocks, truck roads, and landings. Some of the above elements are included in a ‘close-to-best practice’ situation, although usually in a crude form. The planning is mostly executed at forest-camp level and is pretty much a straightforward calculation of the machines and personnel needed, based on the commercial composition of the forest (number and volume of tree to be cut per species). Table 3 shows what is expected to take place under the RIL scenario, according to various publications and completed with impressions obtained at the two sites.

Most of the frequently-mentioned features of the RIL method are already in place at a considerable level at the two research sites. Under the present circumstances, however, the designation of ‘buffer zones’ is based on the abundance of commercial stems. Poorly stocked or hilly areas are left untouched because the cost/benefit ratio of exploiting those areas is too high. No consideration is given to uniqueness or richness of flora or fauna.

Silvicultural aspects, grouped in the ‘tree-selection system’, are rarely, or not at all, mentioned in current publications on RIL. For forests in Fiji, de Vletter (1993) mentions aspects like maximum attainable diameter per species, (10%) reduction for over-maturity, grouping of species, and diameter limits per group. Burgess (1989) also sums up silvicultural considerations: 70% of the trees in the 15-65 cm class are to be retained as growing stock for future harvests, and 40% of the trees in the 65-75 cm class. But hardly touched upon are the number of seed trees to be left standing during harvesting in relation to the distribution of mature individuals per hectare, or the regeneration strategy per species. Yet, when harvesting for sustainable forest management, these aspects must be taken into account.

Figure 1 Logging intensity: number of trees felled per hectare

A striking feature is that, under RIL, the setting of limits to the (absolute) logging intensity is hardly mentioned. It would seem that one might harvest as much as one likes, as long as one does so correctly. This is of course erroneous, as one may still end up with no forest at all. The study in Guyana revealed that by far the most important damage factor was not the logging method, but the exploitation level (Figure 1). Data from Cameroon confirm that, when one is talking about felling damage, intensity is a more decisive factor than the logging method.

Felling patterns (i.e. the distribution of felling gaps over the area) receive very little attention. Should clustered felling, creating multiple tree gaps, be promoted or rather discouraged? Data from the experiment in Guyana show that, if the felling intensity exceeds 8 trees/ha, the accumulated gap area is less in a conventional Greenheart operation (clustered felling) than in the experimental operation (trees to be felled evenly distributed). RIL compensates for this negative effect, however, by a smaller mean gap size. Apparently, we are being confronted with a trade-off. Is there a maximum or minimum gap size before we start talking about damage? Does it depend on the sort of forest we want to end up with? Again, not much has been published in this regard.

Loss of canopy cover as a percentage of total area (black and hatched parts of bars) and ground area affected by skidding (white and hatched parts of bars) as a percentage of total area in a conventional and an RIL operation in Pibiri, Central Guyana. With an intensity of 8 trees/ha, canopy loss is the same with either method, but, with an intensity of 16 trees/ha, it is higher with RIL. On the other hand, skidding damage is markedly more extensive with conventional logging. Also, skidding damage in canopy gaps (hatched parts of bars) is negligible with RIL and extensive with conventional logging. Ground disturbance in gaps will undoubtedly lead to the development of undesirable vegetation.

The interaction with the local population also remains largely beyond the scope of the publications on RIL. Accommodating the usufruct rights of local gatherers by the concessionaires (e.g. by sparing ›social trees: or crop fields) seldom receives attention, and yet the impact of harvesting on the life of the forest dwellers may be considerable. Small adaptations after consultation may well improve the situation at virtually no expense to the concessionaire. In Cameroon, the logging company decides not to cut certain trees, only upon request of the local population and only if the logger thinks the reasons are valid, with a strong inclination towards materialistic reasons rather than customary beliefs.

Climber cutting

Climber cutting is one of the most frequently mentioned tools to reduce felling damage. By cutting climbers some time prior to exploitation, it may be expected that they will have died and that the physical connections binding one crown with another will have weakened considerably. Falling trees may then be less liable to carry down with them their smaller neighbours. Similarly, while felling, fewer trees will be hung up when severed at the base. Studies on the effect of climber cutting on felling damage by Appanah and Putz (1984) and by Fox (1968) showed a substantial reduction of felling damage after climber cutting. Putz (1984) found that climber-infested trees carried down more trees in natural tree falls than did climber-free trees. To ensure that the vine stems have weakened sufficiently, it is recommended that they be cut about one year prior to logging (Pinard,1994), or even two years (Sarre *et al.*, 1996). Cedergren *et al.* (1994) report that pre-felling climber cutting has been found useful when opening skid trails with tractors. They also warn that climber cutting is ecologically questionable, climbers being an important source of food for the fauna. More user- friendly and efficient tools for climber cutting are needed; promising equipment is already available on the market.

In the Pibiri experiment in Guyana, lianas were cut about six months before felling. A comparison of canopy opening due to felling between conventional and experimental logging did not show any clear difference in canopy opening due to liana cutting. Single tree-fall gaps did not differ in area; gaps containing two trees were slightly smaller with experimental felling, whereas multiple tree gaps were larger. The latter two differences were related rather to the felling pattern than to a climber-removal effect. One may argue that the period of six months was too short. Indeed, field observations during felling confirmed that in some cases the climber stems had not weakened sufficiently. Otherwise, there may have been differences in the density of lianas (unconfirmed). Besides climber cutting, there were other differences between the conventional and experimental logging method, specially the felling pattern, which may have concealed an effect of climber cutting. A definite answer to this question would thus require a specific study into the effect of climber cutting.

In Cameroon, a large-scale climber-cutting experiment was set up to test its effects on felling and skidding damage. In the experiment, with 3 treatments and 7-11 repetitions on 1 hectare plots, climbers were cut 9 and 4.5 months before tree felling. Tentative results show that gap size does not decrease with pre-felling climber cutting. Nor was it demonstrated that the level of damage to individual trees had decreased (Parren, 1998). Canopy openness after skid-trail construction with and without climber cutting did not show any great differences either. Again, one may argue that the time that had elapsed after cutting had been too short, but field observations did not confirm this in Cameroon.

Marking of potential crop trees (PCTs) and seed trees

The marking of potential crop trees (PCTs), in combination with directional felling, is frequently cited as an important tool in reducing damage to the (commercially interesting part of the) residual stand. This aspect was only studied in Cameroon and results are not yet available. Questions in this study are: the phase in which tree marking should take place (during or after inventory, during felling) and the visibility of marked PCTs during felling.

In the Guyana experiment, marking of PCTs was deliberately omitted. In this respect, we have to distinguish between preserving PCTs during felling and during skid-trail construction. During felling, attention was given to the retention of PCTs, but this was secondary to achieving the desired felling pattern. The motive behind this was that a trade-off was expected between choosing for a particular felling pattern (herringbone system) and the retention of PCTs. It was argued that any deviation from the felling pattern would increase the extent of ground disturbance, and also that, during log extraction, it would increase the probability of killing trees that were spared during felling. It was found, however, that strict adherence to the felling directions was not absolutely necessary to achieve the desired pattern (van der Hout, 1996; van Leersum, 1984). With regard to safeguarding trees during skid trail construction, this would require important changes in the procedure for skid-trail alignment. The alignment of the skid trails was marked on the ground prior to felling, on the basis of topography and on a fixed distance between trails. Clearly, it is hardly an option to adjust the alignment in order to safeguard a single PCT, for this would result in undesirable winding of the planned trails, while small diversions would probably not even guarantee that marked trees would be spared.

In summary, felling directions can be adjusted to accommodate the safeguarding of PCTs because of the flexibility when extracting logs. Under Guyanese forest conditions, these adjustments can easily take place at the moment of felling (but probably not under Cameroon's forest conditions). To avoid unnecessary killing of PCTs during skid-trail construction, it would be necessary to map PCTs and adjust alignments on a map, because *ad hoc* adjustments would lead to sudden diversions. The pros and cons of including PCTs during the inventory have been discussed above. Whether such an activity is necessary will depend strongly on the abundance of PCTs.

Conclusion

Newly-proposed activities in selective logging in mixed tropical forest are extended planning and subsequent pre-felling forest operations. These, by far, require the most labourious adaptations. If they are to be executed in their most extended form, as suggested now in the various publications on RIL, the implications for current practices will be strong - stronger than in the other harvesting stages. They would require:

- Staff capable of obtaining silvicultural, ecological, and sociological data and including these data in harvesting planning;
- Adequate instruments to elaborate the inventory results and communicate harvest prescriptions;
- Intensive communication between office and forest camp;
- Intensive communication between forest operations.

These implications should be seen against an environment which, at present, possesses far from a proper administration and communication structure.

FELLING

As for felling, many publications deal with what could be called the improvement of conventional felling practices. Making proper felling notches, avoiding undermining of the notch, improved cross-cutting, and so on, are all directives to improve safety and to benefit cut-wood utilisation, which came with the introduction of the chainsaw in tropical forestry in the thirties. Nevertheless, only rudimentary elements of what was once controlled felling are being practised nowadays, because of the poor education system of on-the-job apprenticeship in the forest. The necessity to renew the controlled felling concepts amongst fellers in the tropics is becoming more and more apparent.

The really new concept in the discussion on felling may be directional felling. To master this technique, a more extensive knowledge of mechanics and of the tree's properties would be required. Directional felling is quoted by many authors (Mattsson-Mårn and Jonkers, 1981; Hendrison, 1990; Malmer and Grip, 1990; Gullison and Hardner, 1993; Pinard *et al.*, 1995; Pinard and Putz, 1996; Johns *et al.*, 1996; Cedergren *et al.*, 1994; Whitman *et al.*, 1997) as a new concept for the purposes listed in Table 4.

Table 4 Justification for directional felling under RIL and its validity at two research sites

Purpose	**Cameroon**	**Guyana**
Reduction of damage to potential crop trees	Questionable	Questionable
Facilitation of skidding	No	Yes
Reduction of damage to the felled trunk	No	Yes
Creation of multiple tree gaps	Questionable	Yes

By steering the tree to be felled in a certain direction, the destruction of the surrounding young potential crop trees can supposedly be avoided. Instead of tearing off valuable tree crowns, cut trees may hit commercially less-interesting species instead, or may be directed towards natural gaps in the vegetation.

In both countries, it was proved that directional felling is technically possible. In Cameroon, the large diameters and large buttresses do not hinder a successful execution. Wedges are not needed to make the emergent trees gain momentum for the fall. In the experiment in Guyana, a direction of the lie favourable to skidding was the primary objective. Where possible, trees were felled at obtuse angles (30-45°) to the skid trails for ease of skidding. In the field, the felling direction could be adjusted for the sake of safety to the feller, for the avoidance of damage to the harvested tree and potential crop trees, and for the avoidance of hang-ups. It appeared to be hard to predict how far the impact of a falling tree will reach from the epicentre of its fall, especially when domino effects take place. To be safe, it would probably have been necessary to divert more than 45 degrees from the designated felling direction. Diversions to such an extent would have fouled up the felling pattern and were generally not allowed, but felling in the opposite direction was practised frequently. Despite these efforts, PCTs suffered in the same proportions as non-commercial trees, which means there must have been other reasons for this equality, one of which may be the abundance and dispersion of the PCTs. In Cameroon, simulation with inventory results did not indicate any need to deviate from the natural direction of fall in order to avoid potential destruction of potential crop trees: in whichever direction a tree would be felled, a potential crop tree would be destroyed. In summary, the results from both Guyana and Cameroon indicate that employing directional felling to avoid damage to PCTs is quite equivocal.

Skidding may be facilitated by felling the tree under an angle that makes it easier for a machine to skid or winch the log immediately into the desired direction, instead of having to change the position of the log. The low harvesting levels in Cameroon (Table 1) and the scattered dispersal of the felled trees led to long skidding distances between consecutive logs. These conditions, combined with the impracticability of log winching (see *Skidding* below), are not calling for any scrupulous planning of the direction of fall of a tree. Whatever the angle of the log, the machine could nearly always get to it without deviating too much from the most logical trail pattern.

In Guyana, the extent of skidding damage was reduced tremendously by applying RIL, regardless of logging intensity (Figure 1). This can be mainly contributed to an almost complete reduction of movements around the stump (data not shown). This was achieved by winching the bole to the machine, which in turn was made possible by the favourable position of the logs. As mentioned under *Marking of potential crop trees*, a trade-off between directional felling to safeguard PCTs and directional felling for the ease of skidding is inevitable (although the usefulness of directional felling in retaining PCTs could not be demonstrated by us). This was also pointed out by Cedergren *et al.* (1994), who suggested narrowing down the number of PCTs to be protected through a distinction between PCTs and Next Crop Trees (NCTs). The latter would receive a higher priority for protection. According to their prescriptions, tree crowns should be directed to fall onto skid trails to minimise canopy openings. Such prescriptions would amplify the trade-off, because felling debris on skid trails would have to be chopped up before skid-trail construction.

A reduction in felling damage to the trunk may consist of reducing the loss of wood through breakage when the trunk hits rocky outcrops, felling downhill, suspension of the tree in other crowns, or trees sliding into the bottom of a valley. Under the terrain conditions in the study areas in Guyana and Cameroon, this occurred in less than 1% of the cases.
The creation of multiple tree gaps versus single tree gaps is a question that was highlighted earlier under felling patterns. Directional felling can assist in either of these strategies. Unfortunately, it is not clear which of these strategies should be applied at the two sites.

Results from Guyana showed that the proportion of gaps formed by a single tree, or by two or multiple trees, was influenced both by the logging method and the logging intensity. At an intensity of 8 trees/ha, fewer than most gaps contained less than 3 felled trees with RIL whereas, with conventional logging, 15% of the gaps fell into this class. At an intensity of 16 trees/ha, a quarter of the gaps fell into this class with RIL whereas, with conventional logging, more than half fell in this class. The size of the canopy openings was mainly determined by the number of trees contained in the gap. As mentioned earlier, the total gap area was increased by employing RIL at the highest logging intensity, and apparently we are being confronted with a trade-off. Applying RIL, with its regular felling pattern, is leading to smaller gaps, but also to a higher total gap area when a certain logging intensity is exceeded. Knowing that, in terms of sustainable forestry, large gaps are far less desirable than small gaps (see e.g. ter Steege *et al.*, 1996), one might still opt to employ the experimental logging method. Nonetheless, also from this point of view, it is of paramount importance that an upper limit to the absolute logging intensity is a prerequisite for sustainable forestry,.

Conclusion

Felling standards surely need improvement, but most of them deal with reinforcing the concepts of controlled felling. Directional felling may only be rarely applicable in Cameroon, whereas in Guyana its usefulness is clear, but so, too, is the increased complexity of decisions to be made because of the trade-off between the various purposes of directional felling. Also, it has become crystal-clear that a high logging intensity neutralises the beneficial effects of directional felling.

SKIDDING

Concerning skidding, it may again be useful to distinguish between practices that have been common for the last decades, but have somehow eroded, and totally new concepts. When bulldozers and skidders were first introduced into the scene of tropical forestry, the extraction of wood was based on inventory maps and was closely supervised. These costly machines have never entered the forest without even the slightest planning. Over the last decade, however, supervision of skidding activities in the forest has steadily declined, and also many new, less-well-organised entrepreneurs, copying everything but the planning aspects, have entered the scene.

The new concepts of RIL comprise:

- Detailed planning of the skid trails on the map;
- Detailed alignment of the skid trails in the forest;
- Log winching to the skid trails.

Planning the skid trails

Planning the skid trails as proposed by RIL goes further than the conventional planning of skidding, in principle, intends to go. Where a primary skid trail should pass and where secondary tracks should branch off is no longer a mere indication on the map. Under RIL in its most extreme forms, we may want to plan nearly every movement of the machine and plan the order in which logs are to be extracted. This should all translate into a map with self-explanatory information for the alignment crew.

Skidding in the ›close-to-best practice‹ situation in Cameroon is still portraying some degree of planning, basing itself on maps and some elementary skid trail alignment in the forest by the crew chief just before the machine enters the forest. Post-logging damage patterns also indicate a reasonable amount of planning in the skidding activities. This impression is reinforced through method studies and interviews with crew members. Skidding damage can be reduced (by as much as 30%), not so much through a better planning on the map or in the forest, but through closer supervision during the execution of the skidding and a better transmission of felling results to the skidding crew beforehand.

The results obtained at both sites will be discussed in the sections below.

Alignment of skid trails

Many authors advise signposting or flagging skid trails before actual skidding takes place. Some combine this with marking the trees to be felled or trees to be preserved (de Vletter, 1993). Pinard (1994) proposes that, after the appropriateness of the planned locations has been confirmed in the field, the proposed routes for skid trails and their end-points be marked with paint. In addition, all harvestable trees are painted with a paint slash that indicates the preferred felling direction. Putz (1994) adds the necessity of specifying the construction and use practices. Cedergren *et al.* (1994) aligned their trails at a distance of 60 m, as parallel to one another as nature allowed, following natural borders such as streams and ravines. Sharp curves were avoided and culverts in the trails consisted of hollow logs. The PCTs along the trail were marked. Restricting tractors to ridge tops only would not allow logging at full intensity. There is no reason to believe that skidding would be less efficient on pre-aligned trails - rather the opposite.

While planning primary and secondary skid trails along the contours is already an existing activity in Cameroon (and Suriname), detailed alignment of the skid trail represents an additional harvesting activity. Skid-trail alignment (and construction of the trail) can be done before or after felling. In Cameroon, post-felling alignment of the skid trail was done before the extraction of 165 trees by a Caterpillar (CAT) 528 skidder. The alignment was based on an improved inventory map (scale 1:5000). The marking in the forest was then done in the presence of the skidder operator in order to let him indicate whether or not he could pass certain obstacles or between certain trees. Apparently, the scale of the map (1:5000) was not detailed enough, because this inspection led to important deviations from the planned route. Later, when actually opening up the skid trail, further deviations from the aligned track had to be made because, once the operator was on his machine, the situation proved to be more difficult (i.e. more hilly) than he had originally foreseen. Also, parallel routes had to be created because the carrying capacity of the soil did not permit more than a few passes. Finally, the order in which the logs were extracted changed dramatically because of the inaccessibility of large parts of the terrain after heavy rains. Bulldozers had to be deployed to evacuate most of the wood.

In the Pibiri experiment in Guyana, skid trails were aligned with a 80 m spacing, where topography allowed this. Skid trails were planned on a very detailed map (1:1000), marked in the forest before felling, and constructed after felling by a CAT 528 skidder. The system worked well, but it should be noted that it was intensively supervised. It should also be noted that the scale of the experiment was rather small (cutting blocks of 6 ha only) and that the terrain was rather easy, with sandy soils and few slopes. It is questionable whether such detailed planning and intense supervision is (economically) feasible on a large scale. Surprisingly, the total area of the actual trails was only slightly reduced, compared with a conventional operation. As mentioned under *Felling*, the main beneficial effect of the RIL system was the elimination of movements in the bole zone. Winching is playing a major role in this respect.

Log winching

Log winching (in combination with skid trail planning and alignment) is commonly advocated for its damage-reducing features. It consists of restricting the movements of the extraction machinery to the greatest extent possible. The skid-trail grid is designed in such a way that the machines do not need to deviate from the secondary trails to fetch the logs; these are being winched over distances of up to 30-50 m from the stump to the skid trail. It is strictly prohibited to manoeuvre around the stump to position the log in such a way that the skidding crew can easily attach the cable and proceed; this has been replaced by two crew members pulling the winch cable over a considerable distance. The advantages are twofold: logging damage (around the stump and tertiary trails) is reduced, and machine productivity is considerably increased.

In Guyana, skidding in accordance with the RIL principles proved to be highly effective. Hooking did not present many problems because the majority of the log diameters were below 70 centimetres. Winching distances of up to 30 m were subsequently attained, resulting in a strong decrease in affected ground area (Figure 1). Since winching is playing a decisive role in reducing skidding damage, one might argue that directional felling and skid-trail planning are subordinate and, therefore, could be de-emphasised. Nevertheless, it should be clear that the feasibility of winching depends greatly upon the felling pattern and the skid trail alignment, both being determined by the planned extraction route.

In Cameroon, an experiment with the skidding of 165 trees revealed severe limitations to the applicability of RIL concepts. Hooking, even when a specially designed skidding stick was used to pull the cable underneath the log, proved to be impossible for most of the logs with diameters of over 100 cm and weights of more than 6 tonnes. Winching the log from the stump site frequently yielded the opposite effect, with the machine being pulled to the log instead of the other way round. Most of the supposed beneficial effects in terms of damage reduction therefore proved not to hold true. Table 5 summarises the results obtained at the two sites.

Table 5 Log winching to the skid trail. Tentative results of studies of the two Tropenbos sites

Country	**Activities**		**Effects**	
	Hooking	Winching	Reduction tertiary trails	Reduction manoeuvring
Cameroon	negative	negative	negative	positive
Guyana	positive	positive	positive	positive

Conclusion
Especially when the number of trees harvested per hectare is high and log dimensions are small, as in Guyana, the RIL concept is applicable. In Cameroon, where the opposite prevails, the need and possibilities for a switch is less evident. But, a better organisation and closer supervision of the current skidding phase could already reduce damage considerably.

DISCUSSION

Reduced Impact Logging (RIL) has been hailed as an important step towards sustainable forest management. Given the current state of knowledge, however, it is not clear whether specific practices will actually achieve the desired outcome. One of the reasons for this is that criteria with which to assess the environmental acceptability of various harvesting practices are neither yet fully available nor globally applicable (*cf*. Dykstra, 1996). Most recent publications on this subject seem to agree on an array of activities that will reduce the environmental impact of selective logging in mixed tropical forest. The authors of the present paper have screened these activities against their experiences in Cameroon and Guyana, which has resulted in the following comments on the applicability of RIL.

1. Studies on Reduced Impact Logging (RIL) conducted by Tropenbos in two continents reveal that this concept is not always fully applicable and does (or will) not always lead to less damage than conventional logging practices.
2. Although Reduced Impact Logging is a great step forward, silvicultural, ecological, and sociological considerations need to be added to this technical concept in order to better meet the demands of sustainable forest management, whatever they may be.
3. The set-up and scale of published experiments in which the added value of RIL is being tested are mostly biased and small and not sufficient to convince potential users or legislators.
4. Reduced Impact Logging is an example of developing one of the aspects of ›precision forestry‹ in

the tropics. We can still push for more precision, but improving current conventional practices, taking them to the level of ›the best practice‹, has a far greater impact on forest conservation. The conditions for this improvement lie in better planning, organisation, and supervision in the forest during operations and more adequate training and remuneration of personnel.

5. A careful study of current harvesting practices reveals strong ties between the forest activities on the one hand and, on the other, the demands within the rest of the production chain of the logging enterprise. Even when the economic and financial feasibility of a complete shift towards RIL is clearly demonstrated to a logging enterprise, pressures from outside the forest (and even outside the company) will continue to dictate the forest protocol.
6. The (partial) applicability of RIL guidelines should be taken into account when timber certification schemes are being devised. Non- compliance with what may be globally proclaimed as the solution may have its good reasons locally and may be totally justifiable.
7. On inventory: because of the necessity of integrating silvicultural, ecological, and sociological considerations in logging practices - in Guyana as well as in Cameroon - current inventory practices may need considerable upgrading. Drastic changes in the scale of maps and level of detail during field work, as well as other maps and map-information management, have become inevitable.
8. On pre-felling logging activities: in Guyana as well as in Cameroon, harvest planning following forest inventory will have to shift from a mere ›rule of thumb‹ exercise at the landing site to a more silviculturally-oriented office-level planning process. In this process, attention must be given to the exploitation level, the felling pattern, and the density of potential crop trees and seed trees to be left standing. At forest level, this extended planning will see itself translated into an additional harvest phase before felling, consisting of marking trees to be cut and their direction of fall, marking potential crop trees, and skid-trail alignment. Climber cutting may not necessarily be included in this exercise.

9. On felling: in Guyana, directional felling is an inextricable component of an RIL approach, being a pre-requisite to reducing skidding damage. In Cameroon, although technically feasible, the importance of a shift to directional felling is less evident.
10. On skidding: skid-trail planning and winching are the most promising techniques for Guyana. In Cameroon, winching seems technically impossible in most cases because of the large wood diameters. It may be possible to substantially reduce damage and to increase efficiency by introducing radio communication, skidding sticks, and choker bells, and by reducing blade utilisation.

In summary, the scope for RIL appears to be greater in Guyana than in Cameroon. This is mainly attributable to the higher logging intensity and the smaller log sizes. Nevertheless, it was recognised that the beneficial effects of RIL are strongly tempered if the logging intensity is raised above a certain level. It was also recognised that there is a series of trade-offs that have to be dealt with:

- Directional felling in order to preserve PCTs can adversely affect the ease of skidding and the inherent skidding damage;
- The felling pattern formed by ›herring-bone: felling, being a prerequisite to reducing skidding damage, can, with high logging intensities, lead to a larger total gap area;
- Averting multiple tree-fall gaps, in order to form smaller canopy openings, can lead to a higher total gap area (less overlap of tree-falls).

To deal with these matters, ecological and silvicultural thresholds need to be set. Hence, research questions in the fields of forestry, silviculture, and ecology need to be attuned to one another to investigate these thresholds.

Criteria by which to assess the environmental acceptability of various harvesting practices are thus not yet fully available. Combined with the multiplicity and complexity of the trade-offs that are involved, this means that it is impossible to provide standard RIL recipes. Different approaches may be needed in different places and at different times, even within a single country. Moreover, RIL would require extended planning and pre-felling forest operations, flexible scenarios, and dealing with a series of trade-offs. Even though good harvesting practices may be a prerequisite for sustainable forestry, their introduction will definitely not be easy. Quoting Dykstra (1996) in this respect: ›*If it were easy, the majority of forest harvesting crews around the world would already be doing it, and they are not*Y..:.

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REDUCED IMPACT LOGGING: A GLOBAL PANACEA? COMPARISON OF TWO LOGGING STUDIES

Achievements
- Techniques of Reduced Impact Logging have been developed.
- There is a good insight into the relative contribution of the various field operations to reduce damage and increase efficiency.

Challenges and Problems; Information Needs
- The limited integration of future silvicultural objectives in current logging practices.

Points for Future Research
- Improvement of best current practices of logging.
- Technical and organisational aspects of logging.
- Integration and comparison of logging studies conducted in different localities.
- Research questions in the fields of forestry, silviculture, and ecology must be attuned to one another to investigate the thresholds involved in Reduced Impact Logging.

Conclusions
- Reduced Impact Logging comprises many elements, which are neither always, nor everywhere, nor completely applicable in all situations.
- Silvicultural objectives should, more than is the case at present, be incorporated in the logging strategy. This puts higher requirements on quality and interpretation of the pre-logging inventory.
- While directional felling and winching are important tools in Reduced Impact Logging in Guyana, their application in Cameroon is prevented by technical constraints (the trees are too large).
- Detailed comparisons and combinations of results from logging studies from different research projects greatly enhance our views.
- Although research on forest operations can contribute greatly to the reduction of damage, technological and managerial improvements and political and legal measures are of far greater importance.
- Ecological and forestry research should be matched (e.g. by using create-use matrices).

[1] Best practice means that inputs are used with the highest technical efficiency according to available knowledge and techniques (de Koning *et al*., 1995). Since this is a rather theoretical concept the next best would be >close to best= (or next best) practice.