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Reduced-impact logging: Challenges and opportunities

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ABSTRACT

Over the past two decades, sets of timber harvesting guidelines designed to mitigate the deleterious environmental impacts of tree felling, yarding, and hauling have become known as "reduced-impact logging" (RIL) techniques. Although none of the components of RIL are new, concerns about destructive logging practices and worker safety in the tropics stimulated this recent proliferation of semi-coordinated research and training activities related to timber harvesting. Studies in Southeast Asia, Africa, and South and Central America have clearly documented that the undesired impacts of selective logging on residual stands and soils can be substantially reduced through implementation of a series of recommended logging practices by crews that are appropriately trained, supervised, and compensated. Whether reducing the deleterious impacts of logging also reduces profits seems to depend on site conditions (e.g., terrain, soil trafficability, and riparian areas), whether the profits from illegal activities are included in the baseline, and the perspective from which the economic calculations are made. A standardized approach for calculating logging costs using RILSIM software is advocated to facilitate comparisons and to allow uncoupling RIL practices to evaluate their individual financial costs and benefits. Further complicating the matter is that while there are elements common to all RIL guidelines (e.g., directional felling), other components vary (e.g., slope limits of 17–40° with ground-based yarding). While use of RIL techniques may be considered as a prerequisite for sustaining timber yields (STY), in particular, and sustainable forest management (SFM), in general, RIL should not be confounded with STY and SFM. This confusion is particularly problematic in forests managed for light-demanding species that benefit from both canopy opening and mineral soil exposure as well as where harvesting intensities are high and controlled primarily by minimum diameter cutting limits. These qualifications notwithstanding, since logging is the most intensive of silvicultural treatments in most tropical forests managed for timber, some aspects of RIL are critical (e.g., protection of water courses) whether forests are managed for STY, SFM, or even replacement by agricultural crops.

1. Introduction

Although forest management practices in the tropics are improving, especially in areas certified as well managed by the Forest Stewardship Council (pers. obs.), most tropical timber is still being harvested as if it were not a renewable natural resource: in all ITTO producer member countries, only 3.5% of permanent forest estates are estimated to be sustainably managed (ITTO, 2007). In practice, unfortunately, most logging operations in tropical rainforests are still carried out by untrained and unsupervised tree fellers and skidder drivers working without the benefit of topographic or stand maps, without planned log extraction paths, and without financial incentives to reduce the deleterious environmental impacts of their activities (ITTO, 2007). Consequently, even at low harvesting intensities (e.g., <5 trees extracted per hectare), forests subjected to this conventional logging (CL) lose much of their silvicultural value due to soil damage and damage to future crop trees (FCTs), coupled with the increased likelihood of invasion by lianas and other light-demanding weeds (Putz, 1991). Furthermore, compared with working in other dangerous industries (e.g., mining and off-shore fishing), the International Labor Organization (ILO, 1990) reports that loggers suffer even higher fatality and injury rates.

Tropical foresters have been trying to reduce the avoidable risks to workers and the deleterious environmental impacts of selective logging on residual stands and soils for many years (e.g., Bryant,

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1913; Nicholson, 1958, 1979; Conway, 1976; Jonkers, 1987), but the term "reduced-impact logging" and its acronym (RIL) were apparently first used in 1993 (Putz and Pinard, 1993). RIL can be defined as *intensively planned and carefully controlled timber harvesting conducted by trained workers in ways that minimize the deleterious impacts of logging*. Research on RIL has flourished over the past two decades, with more than 200 publications on the topic (FAO, 2004).

In this paper, we review some of the experimental results of studies in which RIL was conducted in different forest settings. After reviewing RIL and its variations, we compare the silvicultural and financial impacts of RIL and conventional logging (CL). We also address the dangers of equating RIL with full forest management, particularly where the principal control on logging intensity is the minimum diameter tree that can be legally harvested. We hope that this review provides a basis for improving RIL and taking further steps towards the goals of sustained timber yields (STY) and sustainable forest management (SFM).

2. RIL guidelines and reduction of logging damage

Detailed RIL guidelines developed in Australia (Queensland Department of Forests, 1988) and those widely circulated by FAO (Dykstra and Heinrich, 1996) served as templates for developing more locally tailored sets in several regions in the tropics. For example, RIL codes-of-practice were subsequently developed in Asia and the Pacific (FAO, 1999), Brazil (Sabogal et al., 2000), Malaysia (Forest Department Peninsular Malaysia, 2003), and West and Central Africa (FAO, 2003). Most RIL guidelines are also components of most forest management plans and start with recommendations related to designation of forest management units and progress rapidly through issues related to assignment of annual coupes (i.e., cutting areas) before considering in more detail issues related to road and log landing planning, layout, and construction. Methods are usually described for the construction of bridges, culverts, and other water course-related structures. Pre-harvest stand mapping always includes marking of trees to be felled and skid trail planning, whereas the mapping and marking of future crop trees (FCTs) and pre-harvest liana cutting are less consistently included in packages of RIL practices. Central to all RIL guidelines is the use of felling techniques that increase worker safety, reduce wood waste, and direct the fall of trees to facilitate extraction and protect FCTs. Last but not least are specified management unit closure operations including post-harvest assessments to provide feedback to forest authorities, forest owners, concession holders, and logging crews on the success with which RIL guidelines were implemented.

Developers of RIL guidelines strive to balance between being overly prescriptive and not being specific enough; not surprisingly, many different balance points have been reached. In regards to skid trail closure operations, for example, whereas the RIL guidelines for Sabah, Malaysia and Vanuatu both specify the required spacing between cross-drains as a function of slope (e.g., 20–30 m for slopes 5–15°; Lohuji and Taumas, 1998; Vanuatu Department of Forests, 1998), those for Peninsular Malaysia just indicate that cross-drains should be installed on "critical stretches and roads with steep gradient" (Forest Department of Peninsular Malaysia, 2003). Where guidelines are very detailed, loggers might justifiably point out that rates of soil loss vary with more than simply slope, and argue that factors such as soil type and the presence of logging debris should be included in the determination of inter-drain spacing. In contrast, where drain spacing rules are not specified, forest auditors have a weaker basis on which to judge whether a logging operation is in compliance with road and skid trail closure requirements.

When RIL guidelines are specific, they vary from country to country in sometimes alarming ways. For example, Conway (1976) long ago pointed out that residual stand, soil, and log damage are excessive on slopes >17°, which Dykstra and Heinrich (1996) note is the upper slope limit for ground-based yarding in many countries. Nevertheless, RIL specified slope limits range from 15° in Indonesia (Sist et al., 1998b), to 25° in Sabah, Malaysia (Lohuji and Taumas, 1998) and 30° in Vanuatu (Vanuatu Department of Forests, 1998), to 40° in Peninsular Malaysia (Forest Department of Peninsular Malaysia, 2003).

Given the wide variation in the silvics of tropical tree species and the often substantial ecological differences among the forests from which they are harvested, coupled with differences in yarding methods and the variety of objectives of different forest managers, appropriate RIL guidelines must continue to vary among forests. In other words, other than in the most general terms, there is and should never be a universal set of RIL practices. Another cause for differences among RIL guidelines is continuing disagreements among logging experts about how to best harvest timber. For example, the RIL guidelines used in an industrial-scale logging project in Sabah (Pinard et al., 1995) call for maximizing the distances over which logs are winched so as to minimize the damage caused by the crawler tractors used in log yarding. In contrast, J. Zweede (pers. comm.) recommends that the articulated skidders with rubber tires used for log yarding in Brazil drive directly up to the logs so as to minimize the amount of soil they plow up while being winched across the surface. In either case, when the front end of a log is elevated above the ground, as it is when yarded using a logging arch or a winch mounted high on the tractor or skidder, or when a cone or skidding pan is attached to the front end of the logs, this sort of surface damage can be reduced (Conway, 1976); unfortunately, such innovations are sometimes cumbersome and otherwise not widely used.

Basic implementation of RIL requires detailed inventories in which the trees to be harvested are mapped, marked, and measured. In the Amazon, some foresters, mainly those working with non-industrial small scale private forest owners or communities, also mark and map the most important species providing non-timber forest product (e.g., *Carapa guianensis* and *Dipteryx odorata*). The minimum diameter of trees to be inventoried varies widely according to the region and the specified minimum cutting diameter, which itself can also vary by species. Despite the many benefits of mapping and marking FCTs especially where they are rare, including substantial reductions in the logging damage they suffer (e.g., Krueger, 2004), this practice is not consistently included in RIL guidelines. In most cases, pre-logging forest inventories are only used to plan harvesting operations (e.g., directional felling and skid trail locations), whereas if FCTs are also mapped, the post-logging silvicultural treatments generally needed to sustain timber yields are greatly facilitated.

Reducing soil damage is a major emphasis of RIL where logging operations are carried out on steep slopes using heavy ground-based yarding machines on wet soil with low trafficability (e.g., Pinard et al., 1995). In contrast, where logging is restricted to the dry season and the terrain is gentle, such as in much of the Amazon, soil damage, in general, and soil compaction, in particular, receive less attention (Fredericksen and Putz, 2003). Nevertheless, even on level terrain, roads, skid trails, and especially stream crossings deserve a great deal of attention from forest managers. Unfortunately, despite the high costs of construction and maintenance of the transportation infrastructure in logging areas, few forest engineers are employed by logging companies and few foresters are being adequately trained in the planning, layout, and construction of logging roads and skid trails. In any event, while the details of design, implementation, and analysis vary, the overall message from the published experimental comparisons of RIL and CL is that soil damage and can be reduced by 25–50% (e.g., Pinard et al., 1995; Johns et al., 1996; Pinard and Putz, 1996; Bertault and Sist, 1997; van der Hout, 1999; Sist, 2000, 2003; Pereira et al., 2002).

Detailed comparisons of the residual stand damage caused by different logging techniques are made difficult by the lack of a standardized system for scoring tree damage. For example, Jackson et al. (2002) and, later, Krueger (2004) used three categories to score logging damage to tree boles (in decreasing order of severity): snapped at base or severely bent/leaning; exposed and damaged cambial tissue; and exposed cambial tissue but no damage, bark scrape. In contrast, Feldpausch et al. (2005) used four categories to describe bole damage: "trunk broken; >2 m bark missing; <2 m bark missing; and, tree bumped and at an angle." While standardization of damage criteria is necessary for comparing studies, it is also important to note that cambial tissue never survives exposure so that even after small pieces of bark are removed, the xylem is open to pathogen invasion. Whether trees successfully compartmentalize decay in the xylem and close bark wounds vary with the amount of bark removed, tree vigor, and species-specific characteristics (Romero and Bolker, 2008). Nevertheless, all trees will retain pockets of rot in their stems after even minor damage, and more severe cambial damage will, over the next decades, result in heartrots in many trees. The appropriate level of detail used in scoring logging damage is an issue with which researchers will continue to grapple, but standardized and biologically sound methods are definitely needed.

Liana cutting before timber harvesting is recommended in most RIL guidelines (e.g., Dykstra and Heinrich, 1996), but the caveat "where necessary" is typically and justifiably registered. Where large woody lianas connect the crowns of crop trees to their neighbors, tree felling has been demonstrated to be both dangerous to workers and unnecessarily destructive to the residual stand (e.g., Fox, 1968; Appanah and Putz, 1984). In Bolivian forests where large lianas are exceedingly abundant, pre-felling liana cutting is one of the RIL recommendations that is consistently applied by logging crews out of concern for their own safety. These observations notwithstanding, liana cutting on trees to be harvested is not worthwhile where lianas are scarce, small, or weak (Parren and Bongers, 2001; Rockwell et al., 2007). Finally, while it is probably always silviculturally wise to liberate FCTs from lianas (Putz, 1991), this treatment is seldom specified in RIL guidelines.

3. Economics of RIL

One of the most controversial aspects of RIL is the question of the financial burden it may place on loggers. Concerns about this potential burden are often expressed as a major constraint inhibiting widespread adoption of RIL (Putz et al., 2000). For example, at an international conference on RIL in 2001, Barney Chan of the Sarawak Timber Association (Malaysia) challenged advocates of RIL to prove definitively that the acronym does not stand for "reduced-*income* logging," which he said is a major concern of the timber industry in tropical countries (Enters et al., 2002).

Loggers implementing RIL practices frequently must adopt new ways of working, invest in new equipment and safety gear, re-train their crews, and hire technically qualified supervisors to plan and oversee the work (Pokorny et al., 2005). Such requirements impose incremental costs that conventional logging (CL) operators avoid, potentially putting RIL operators at a financial disadvantage. In some cases, RIL specifications effectively re-zone the forest so that large blocks of steep terrain or wet soils can only be logged with expensive helicopter or cable systems, or not at all (Pinard and Putz, 1996). Reductions in the net area harvested, even if it simply entails obeying the law, can have major impacts on the overall profits to concessionaires or forest owners, particularly at the relatively high discount rates and with the policy implementation failures common in tropical countries (Healey et al., 2000; Smith et al., 2006).

Research reports on the relative costs of RIL date back more than 25 years to a seminal paper by Mattson Marn and Jonkers (1981). Based on a comprehensive forest inventory, these authors found that conventional loggers missed as much as 20% of the merchantable volume in felled tree stems. This loss was attributed to the fact that the loggers worked without advance planning and with felling and skidding crews operating independently. After felling was completed, skidding crews arrived to remove as many felled stems as they could locate. Working in dense forests without maps, even though skidder drivers opened more skid trails than necessary, they still missed logs on which the cost of felling and bucking had already been paid. The result was a financial loss to the logger and the concession owner, and both economic and environmental losses to society at large. Nearly all economic studies of conventional logging operations conducted since that study have also found that some merchantable logs are left behind in the forest (Barretto et al., 1998; Holmes et al., 2002; Dwiprabowo et al., 2002), and rates as high as 20% are still being reported (Richter, 2002). When combined with the losses in the typically higher stumps and higher frequency of log splitting, it is clear that conventional loggers waste a lot of wood whereas those practicing RIL leave behind comparatively little merchantable timber.

Although several comprehensive financial comparisons of RIL and CL have been published (Barretto et al., 1998; Boltz et al., 2001; Bull et al., 2001; Winkler and Nöbauer, 2001; Applegate, 2002; Dwiprabowo et al., 2002; Fath, 2002; Holmes et al., 2002; Richter, 2002; Applegate et al., 2004), their findings vary. The reported results seem to depend on forest and terrain conditions, competence of logging crews, methods of compensating loggers, timber markets, and other factors. In some studies (e.g., Holmes et al., 2002), RIL operations have been shown to be clearly more favorable financially than CL operations, due in large part to a reduction in wastage of merchantable timber where RIL is applied. Other studies have reported just the opposite, especially when the cost of foregone timber due to RIL (on steep slopes or in stream buffers, for instance) is incorporated into the analysis (Healey et al., 2000). Still others have shown mixed results. Applegate (2002), for example, summarized four case studies in which two RIL operations gave better financial results than CL operations in the same area, whereas the CL operations proved financially more favorable in the other pair of compared cases.

Whether RIL or CL is more financially profitable depends a great deal on the perspective from which the costs and benefits are calculated (Applegate et al., 2004). In particular, there are to be expected differences in perspective between forest owners, timber companies, logging contractors, and forest workers. Each of these firms has a legitimate point of view, but conflicting perspectives can result in unintended inefficiencies with negative effects on costs and revenues. For example, forest owners are likely to take the long-term consequences of poor logging practices into consideration more than loggers with short-term contracts. An even more insidious but likely conflict is when concessionaires resist the training and consequent professionalization of their workers because they worry about having to provide higher salaries and better working conditions. Finally, as long as forest owners, concessionaires, and logging contractors are allowed to avoid assuming financial responsibility for the safety of their workers, continued disregard of the recommended safety practices in RIL guidelines is likely (ILO, 1998).

It is not possible to draw general conclusions about the financial performance of RIL as compared to CL operations simply because of the extremely wide range of forest conditions, labor compensation practices, availability of skilled personnel, timber markets, and other factors that influence the profitability of logging operations in the tropics. Other impediments to making conclusive comparisons are methodological but at least two tested approaches are available that enable timber companies and other interested parties to compare the costs of RIL and CL under local conditions. One of these approaches involves monitoring operations and obtaining cost data through collaboration between timber companies and research organizations (Pokorny and Steinbrenner, 2005). The methodology provides information on costs and production rates that is useful for the timber company, while providing the researchers access to data on harvesting operations. The authors note, however, that substantial investments in time and personnel are required for the procedure to work properly, and suggest that it is therefore unlikely to be adopted except by companies interested in having their operations certified under a sustainable management protocol.

The second approach to comparing the financial costs and benefits of RIL and CL utilizes an open-source, financial-analysis software package, RILSIM (Reduced-Impact Logging SIMulator; Dykstra, 2004). Users of RILSIM enter information through a series of data forms to describe payroll costs, personnel assignments, equipment costs, logging activities, expected production rates, and other factors relevant to a logging-cost analysis. Running the simulator then produces a detailed report of costs and revenues, as well as an estimated timeline for the operation being evaluated. Both current and discounted costs and revenues, utilizing the discount rate set by the user, are provided. With this user-friendly software loaded on a personal computer, logging firms can also privately simulate the financial consequences of implementing only a portion of the recommended RIL practices, a repeatedly requested option. Widespread adoption of RILSIM as a standardized method for estimating the costs, revenues, and expected operating time for a logging operation would greatly facilitate inter-site comparisons. Furthermore, the simulation package allows rapid evaluation of different assumptions as well as changes in production rates or cost structures (e.g., a change in payroll tax rates). A disadvantage of the software is that it only considers direct costs and revenues associated with logging—broader issues such as foregone revenue from areas that cannot be logged under RIL rules must be evaluated in some other way.

Many of the benefits of RIL are enjoyed by stakeholders outside of the forest and otherwise not directly involved in the logging business. In the sort of comparative financial analysis facilitated by RILSIM, these broader economic concerns are not considered. Nevertheless, given the modest profit margins and high opportunity costs of long-term management of natural tropical forests for timber, capturing some of these "externalities" in cost-benefit analyses is often critical (e.g., Pearce et al., 2002; Chomitz, 2007). For example, RIL might be promoted where conventional logging practices might otherwise be employed in the name of biodiversity (Putz et al., 2001; Meijaard et al., 2005). Ample evidence is already available that selective logging using RIL techniques increases forest retention of carbon relative to conventionally logging (Pinard and Putz, 1996, 1997; Pinard and Cropper, 2000; Pinard et al., 2000; Keller et al., 2004; Feldpausch et al., 2005; Keller et al., 2007). Although improved forest management was not included in the Kyoto Protocol as an option for carbon sequestration and despite the fact that forest management of any sort is disfavored by many environmentalists (Putz, 2004), forests in which RIL techniques are employed should soon be eligible for environmental service payments from the rapidly developing voluntary international markets for carbon, hydrological services, and biodiversity (Wunder, 2007).

4. Steps beyond RIL towards STY and SFM

After decades of experimentation and encouraging cases of large-scale implementation (Pokorny et al., 2005), RIL is now widely recognized as an essential component of sustainable timber harvesting prescriptions (Putz et al., 2001; Fimbel et al., 2001; Sist et al., 2003; Sist and Ferreira, 2007). Nevertheless, it is critical to remember that RIL guidelines are designed mainly to mitigate the deleterious impacts of timber harvesting and do not address many the issues related to sustaining timber yields (STY) or sustainable forest management (SFM). Indeed, most studies on RIL in which timber yields were monitored or modeled concluded that RIL alone does not guarantee that subsequent harvests will produce similar volumes of comparable timber quality as the first cut (Fredericksen et al., 2003; De Graaf, 2000; Sist et al., 2003; Kammesheidt et al., 2001; Dauber et al., 2005; Sist and Ferreira, 2007; Van Gardingen et al., 2003, 2006, Schulze et al. this volume). For example, Sist and Ferreira (2007) report that after harvesting 21 m^3/ha from a moist lowland forest in Brazil using RIL practices, the next planned harvest, 30 years later, would yield 50% of the first. Worse yet, Dauber et al. (2005) predicted that after harvesting only 11.8 m^3/ha from a heavily liana-infested Amazonian moist forest in lowland Bolivia using RIL practices, the yield at the end of the intended cutting cycle (25 years) would only be 21% of the initial harvest.

RIL also fails to achieve the silvicultural goal of sustaining yields in forests that are very well stocked with timber but where harvests are guided principally by minimum diameter limits. In such forests, which were once widespread in Southeast Asia, extraction rates often exceed 100 m^3/ha. At such high harvesting intensities, even where RIL methods are used, damage to the residual stand can exceed 50% and future yields, biodiversity, and ecosystem functions are all compromised (Nicholson, 1979; Pinard and Putz, 1996, 1997; Bertault and Sist, 1997; Sist et al., 1998a, 2003; Putz et al., 2001). Using RIL techniques, but limiting logging intensities and extending cutting cycles, are obvious prerequisites for sustaining the yields and maintaining the other values of such forests, but additional silvicultural interventions might also be needed (Sist et al., 2003; Sist and Ferreira, 2007). Unfortunately, such innovations in forest management practices on beyond RIL towards STY and SFM are unlikely to be adopted spontaneously because they shrink the short-term profitability of logging by permitting fewer trees to be harvested per hectare to cover the fixed costs of roads and other infrastructure (Walters et al., 2005; Karsenty and Gourlet-Fleury, 2006).

Silvicultural treatments often need to be applied to keep forests healthy and productive, but the intensity of the required interventions varies among forests. For example, where the harvested species are represented by abundant advanced regeneration (i.e., seedlings, saplings, poles, and trees smaller than the size harvested; i.e., FCTs), RIL alone could be sufficient to sustain yields as long as logging intensities are modest and cutting cycles are long (Durrieu de Madron and Forni, 1997; Sist et al., 2003; Sist and Ferreira, 2007; Valle et al., 2007).

The silvicultural treatments beyond RIL that are required to sustain timber yields are often straightforward to apply and can be cost effective. For example, liberation from lianas and competition from non-merchantable neighboring trees has been shown to increase markedly the growth rates of FCTs at minimal cost (e.g., Guariguata, 1999; Wadsworth and Zweede, 2006). Unfortunately, the long-term impacts of such treatments on growth rates, forest structure, and composition are still hard to predict (Silva et al., 1995; Gourlet-Fleury et al., 2004; Van Gardingen et al., 2006). Such weaknesses in the scientific basis for tropical forest management are difficult to accept given the large number of established sample plots that could yield the relevant data, but many of these data remain un-analyzed or buried in poorly circulated project reports. In any event, operational scale post-logging silvicultural treatments of any sort are still rare in tropical forests. We suggest that in addition to unearthing the relevant results hidden in the grey literature, researchers move beyond comparisons of RIL and conventional logging towards studies on pre- and post-RIL silvicultural treatments

Timber yields can decline in forests harvested using RIL techniques where the pattern and intensity of logging are not silviculturally appropriate. Such mismatches are common because, although it is generally recognized that substantial canopy openings and sometimes even soil disturbances are required to secure regeneration of light-demanding and small-seeded species (e.g., Fredericksen et al., 2003; Dickinson et al., 2000; Snook, 1996; Pariona et al., 2003; Putz and Fredericksen, 2004; but see Sist and Brown, 2004), environmentalists and even ecologists (e.g., Foley et al., 2007) often equate the maintenance of pre-logging forest structure with good management. Admittedly, canopy disturbances cause forest understories to be drier and more fire prone (e.g., Holdsworth and Uhl, 1997, but see Blate, 2005), but if yields of commercially important light-demanding species are to be sustained (e.g., *Swietenia macrophylla*, *Cedrela* spp., *Entandrophragma* spp., and *Shorea leprosula*), then minimizing changes in canopy cover is not a logical silvicultural goal. One cause of this common misunderstanding is the assumption that tropical forests and tree populations are generally at equilibrium before the first modern logging intervention whereas many are still recovering from severe but unrecorded natural or anthropogenic disturbances (e.g., Denevan, 1992). These observations notwithstanding, given the propensity of large openings to be colonized by light-demanding weeds such as bamboos and lianas, silvicultural recommendations involving substantial changes in canopy cover should be made with caution (Sist and Brown, 2004).

Although much of the literature on RIL focuses on industrial-scale management of tropical forests for timber, given the vast and increasing areas of tropical forest in the control of rural communities and private non-industrial forest owners (White and Martin, 2002), the particular needs of these potential forest managers should be addressed. For example, compared to their industrial counterparts, small-scale forest managers are often more interested in non-timber forest resources, cultural amenities, ecotourism opportunities, and environmental service payments (Sheil and Van Heist, 2000). Non-industrial forest managers also typically multi-task when applying silvicultural treatments, which complicates economic evaluations but makes such interventions more likely (Putz, 2000).

Whereas there are reasons to doubt whether many forest stakeholders will be willing to pay the financial and ecological costs of STY (e.g., Pearce et al., 2002; Luckert and Williamson, 2005; Karsenty and Gourlet-Fleury, 2006), the benefits of most RIL practices are widely appreciated. For example, even in forests being selectively logged as a preliminary step in the conversion process, RIL techniques such as skid trail planning and directional felling should be used to avoid the sorts of soil damage that can reduce plantation or pasture productivity for decades. Similarly, use of RIL techniques generally increases timber yields and logging profits while reducing other environmental damages as well as the personal hazards suffered by forest workers. As an extension of this RIL-based win-win situation, at a modest cost (e.g., \$1000 per worker in Brazil; Keller et al., 2007), RIL training serve to stimulate professionalism in the workforce and should thereby help turn the tide of illegal logging (Ravenal et al., 2004). More broadly, if RIL training opportunities were more widely available, the trained workers would help in the conversion of the culture of forest exploiters to one that is more sensitive to the goal of SFM including maintenance of biodiversity, protection of hydrological functions, and reduction of emissions of atmospheric heat trapping gases from managed forests.

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