Financial Indicators of Reduced Impact Logging Performance in Brazil:
Case Study Comparisons

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ABSTRACT

Indicators of financial performance are compared for three case studies in the Brazilian Amazon. Each case study presents parameters obtained from monitoring initial harvest entries into primary forests for reduced impact logging (RIL) and conventional logging (CL) operations. Differences in cost definitions and data collection protocols complicate the analysis, and suggest that caution is necessary in interpreting results. Given this caveat, it appears that RIL can be competitive with or superior to CL in financial returns to initial harvest entries if the financial costs of wood wasted in the harvesting operation are fully accounted for. Standardization of study methods, and replication of studies across different forest types, levels of industrial scale and markets, would allow more rigorous tests to be made of RIL relative profitability. Adoption of RIL techniques as part of a long-term forest management system faces additional challenges related to the opportunity cost of timber set aside to maintain productivity and ecosystem integrity, as well as issues regarding land tenure security.

Introduction

The neo-classical theory of the firm is built on the presumption that businesses attempt to maximize profits, where financial profits are simply the difference between the revenue received by a firm and the costs it incurs. Economic theory says that, for a given technology, the firm evaluates the various ways it can utilize labor, land and capital inputs to produce outputs. Maximum profits are gained by choosing input levels so that the value of the marginal product produced by each input is equal to its cost (Varian 1984). If inputs to the production process are non-priced (such as environmental quality), or under-priced (such as standing timber) then they will be over-utilized from a social perspective. In the case of forestry, the result has historically been timber mining, degradation of environmental quality and industrial migration.

The cycle of timber depletion, environmental degradation and industrial migration is not a new story. It occurred in the primary forests of the United States (Williams 1989) and has proceeded to such tropical countries as Brazil (Nepstad et *al.* 1999). The demand for tropical timbers suggests that this process will continue unless significant changes in technology and/or policy are implemented. Tropical forests formerly under little pressure for timber production are now increasingly the focus of logging industry development, Growth in the Latin American and African share of total tropical timber production will likely continue to beyond turn century, as few Asian countries have the potential to substantially increase sustainable log production (ITT0 1996). Recent trends in tropical timber production show a decrease in the Asia-Pacific region's share of global production by 29.6 percent from 1992 through 1999. Production in the Latin America-Caribbean region increased 15.8 percent over this same period (ITT0 1999).

Conventional logging (CL) practices are recognized as a principal contributor to degradation and ultimate conversion of tropical forest ecosystems to nonforest land uses (e.g., Johnson and Cabarle 1993, Bryant et *al.* 1997). The decreased productivity of forests following damaging CL entries may translate into higher opportunity costs for long-term forest management and greater incentive for the conversion of forestland to alternative uses.

Reduced-impact logging (RIL) practices comprise harvest planning, infrastructure development and operational techniques which aim to reduce the damaging impacts of timber harvest while improving the production efficiency of logging operations. The FAO model code of forest harvesting (Dykstra and Heinrich 1996) provides the basis for RIL system design. RIL techniques and guidelines are not fixed prescriptions, but adapt best harvesting techniques to existing biophysical and economic conditions. Throughout the tropics, RIL has proven more ecologically benign than conventional logging activities (e.g., Boxman et a/. 1985, Johns et al. 1996, Pinard and Putz 1996, Uhl et al. 1997). Furthermore, RIL has been shown to reduce operational costs (Boxman et *al.* 1985) and, in some cases, generate higher initial financial returns than conventional operations (Barreto et *al.* 1998, Holmes et *a/.* 2000). RIL systems may provide a low cost method of maintaining the carbon sequestration functions (Putz and Pinard 1993, Boscolo et *a/.* 1997) and structural diversity of tropical forests (Frumhoff and Losos 1998). However, it has not been demonstrated that RIL operations alone are sufficient for the sustained production of merchantable timber or for the maintenance of the environmental service flows provided by tropical forests in their natural, unaltered state.

Financial self-interest is a strong motivating force. Understanding the financial aspects of RIL under different ecological, industrial and market conditions is imperative if sustainable forest management is ever to become a reality in tropical forests. If a "feasible financial set" of conditions is identified where RIL is more profitable than conventional logging (CL) practices, then self-interest may help protect ecological services after initial harvest entries in some logged tropical forests.

In this paper, we compare indicators of financial performance for three case studies in the Brazilian Amazon. To conduct the analysis, we decompose case study results into common measures of productivity, cost and profitability. Direct comparisons are complicated by the fact that standard protocols were not used across studies. To provide a tractable analysis, we utilize incremental measures, where increments measure proportional changes between CL and RIL systems.

Case Studies

International donors and the private sector funded the following studies conducted during the mid-1990s

1. **Agrosete** (Barreto et *al*. 1998, Johns et *al*. 1996): The RIL-CL comparison was conducted in private forestland of Fazenda Agrosete, approximately 20 km southeast of Paragominas, Pará, Brazil (3" S; 47.5' W). RIL was conducted on a 105 ha plot and CL on an adjacent 75 ha plot. Trained operators worked with the research team on the CL and RIL plots.[1] RIL extracted 4.5 and CL 5.6 trees per ha. Productivity, cost, and waste wood measures were drawn from observed operations and plot impacts. Lowland, closed-canopy *terra firme* forests of Paragominas are humid, evergreen with a canopy height of 25 to 40m and emergents extending to 50m. The terrain is moderately undulating and soils are kaolinitic red-yellow oxisols. Annual rainfall averages 1750mm with a distinct dry season from June to November. Mean annual temperature is 28^o C.

2. **Cauaxi** (Holmes et *al*. 2000): Research was conducted in private forestland of the CIKEL timber company on Fazenda Cauaxi, some 120 km southwest of Paragominas, Brazil (3^o S; 47.5" W). RIL was conducted by trained operators of Fundação Floresta Tropical (FFT) on 100 ha of undisturbed forest, while CL was implemented by local contractors hired by CIKEL in an adjacent 100 ha plot. CL harvested 39 and RIL 41 timber species, at intensities of 4.25 and 3.31 trees per hectare (ha), respectively. Logging intensity and waste wood measures were collected in the Cauaxi plots. Average productivity and cost measures for the study were calculated from a sample of FFT RIL operations and CL operations in the Paragominas region. The study was also conducted in lowland, closed-canopy *terra firme* forests of the Paragominas timbershed (see *Agrosete* above for ecosystem description).

3. **Itacoatiara** (Winkler 1997): The study examined private forestland of Mil Madeireira Itacoatiara S.A., a Brazilian subsidiary of Precious Woods, Ltd., which is located 227km east of Manaus (3^o S; 59^o W). Efficiency and environmental impact studies were conducted in two adjacent 10 ha cutting blocks. Production costs per component were estimated as a proportion of total logging costs, while specific per unit costs were not reported. Both RIL and CL operations were implemented by the Precious Woods, Ltd. logging team. CL removed 16 and RIL 6 trees per ha, or 78.9 percent and 26.9 percent of the available merchantable volume per plot. Sixty-five tree species are of commercial interest, of which 24 were harvested under RIL and 32 under CL. The lowland, moist *terra-firme* forests lie upon inclined plateaus of Tertiary origin. Steep ravines dissect the

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[1] Two RIL operations were examined, one using a bulldozer fcr skidding and the other using a rubber-tired skidder. Directional felling was conducted by both Z-person and 3-person teams. We include costs and productivity for 2-person felling with RIL bulldozer data and for 3-person with RIL skidder data.

plateaus at slopes of 10" to 40° (Precious Woods 1997). Soils are oxisols. Canopy height is 30 to 37m with emergents extending to 55m. Annual rainfall is around 2200mm with a dry season from June to October. Mean annual temperature is 26 ° C.

Table 1. Timber harvesting characteristics and financial cost estimates from three studies in the Brazilian Amazon

	Fazenda Agrosete		Fazenda Cauaxi		Mil Madeireira Itacoatiara	
Harvest Variables	Conventional Logging	Reduced Impact Logging	Conventional Logging	Reduced Impact Logging	Conventional Logging	Reduced Impact Logging
Plot size	75 ha.	100 ha.	100 ha.	100 ha.	10 ha.	10 ha.
No. of trees harvested (net area)	5.6/ha.	4.5/ha.	4.25/ha.	3 31/ha.	16/ha.	6/ha.
Volume harvested (net area)	29.7m^3/ha.	38 6m^3/ha.	25.4m^3/ha.	25.4m^3/ha.	92.7m^3/ha.	36.5m^3/ha.
Skidding machines	Caterpillar D5B bulldozer	Caterpillar 518C rubber tire skidder with winch and grapple and Caterpillar D5E bulldozer with winch.	Caterpillar D6 Logger bulldozer with winch	Caterpillar 525 rubber tire skidder with winch and grapple	Caterpillar 518C rubber tire skidder with winch	Pre-skidding using D4H TSK bulldozer with winch. Skidding using Caterpillar 518C rubber tire skidder with winch
Road building machines	Caterpillar D5B bulldozer	Caterpillar D5B bulldozer	Caterpillar D6 Logger bulldozer	Caterpillar D6 SR bulldozer	Caterpillar D8 bulldozer	Caterpillar D8 bulldozer
costs	Based on gross area	Based on gross area	Based on standard volume	Based on standard volume	Based on gross area	Based on gross area
Planning		$1.87/$m^3$	$0.14/$m^3$	$1.34/ m^3		15% of total
Felling	$0.30/$m^3$	$0.31/$m^3$ (2 person) $0.25/$m^3$ (3 person)	$0.491 m^3	$0.62/ m^3	10% of total	12% of total
Skidding - to landing	$1.37/$m^3$	$1.31/$m^3$	$1.99/ m^3	$1.24/ m^3	63% of total	39% of total
Opening roads and log decks	$0.41/$m^3$	$0.28/$m^3$	$0.57/$m^3$	$0.32/$m^3$ + $0.27/$m^3$ skid trail layout	27% of total	24% of total
Log deck operations	$2.59/$m^3$	$2.59/$m^3$	$2.01/$m^3$	$1.28/$m^3$		
Total direct	$4.67/$m^3$	$6.30/$m^3$	$5.20	$5.07	100%	100%
Stumpage	$6.66/$m^3$	$5.00/$m^3$	$9.09/$m^3$	$7.61/$m^3$		

Table 1 shows the general timber harvest characteristics as well as providing a summary of relevant cost data at the three study sites. Variation in harvest intensity, particularly at Itacoatiara, is observed. Because logging costs generally decrease, up to some point, as harvest intensity increases, large differences in harvest intensity may obfuscate meaningful comparisons. In addition, the reader is warned that comparisons of cost data can be misleading because identical activities may or may not be included in each cost category, and different protocols may have been used to collect data. Further, cost data from Itacoatiara are not presented in monetary units, but only as percentages of total cost. However, the authors were careful in constructing Table 1, and it presents a summarization of the best comparative data available regarding RIL and CL parameters in the Brazilian Amazon.

Productivity Comparisons

Directional felling productivity is more time consuming and thus less productive under R/L when R/L and CL extract similar volumes and target stems (Fig. 1). CL sawyers were 10 percent to 22 percent more productive in volume produced per hour ($m^3 hr^{-1}$) than comparable RIL felling teams. Importantly, at Fazenda Agrosete, Barreto et *al.* (1998) found that gains in directional felling productivity by a 3-person team rendered RIL more efficient than CL 2-person felling. On average, the 3-person RIL team felled 34 trees per day relative to the 22 trees felled by 2 CL sawyers. Productivity gains exceeded the increased cost of labor and equipment for the 3-person team. At Itacoatiara, Winkler (1997) found that felling time per stem was higher under RIL. However, because the RIL operation focused on "only the most mature trees of commercial interest", greater volume per stem was recovered in RIL felling operations, resulting in its greater efficiency relative to CL.

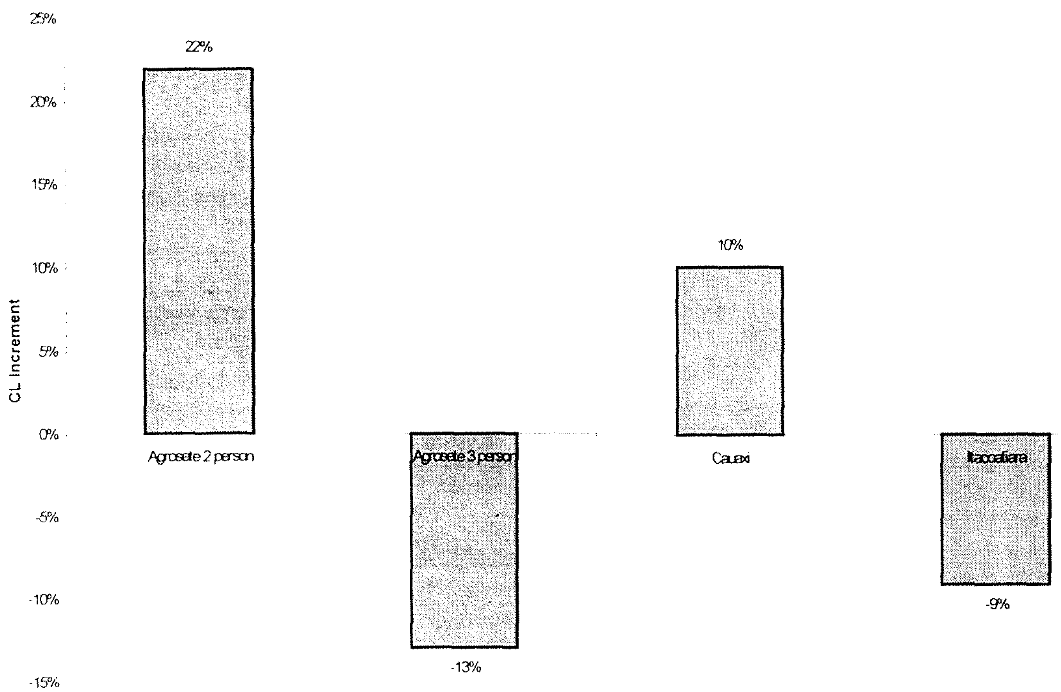

Figure 1. Incremental productivity of CL felling ($m^3 hr^{-1}$), computed as (CL productivity - RIL productivity)/RIL productivity.

Skidding operations are more productive under RIL due to efficient planning and infrastructure development that facilitates stem extraction (Fig. 2). RIL utilizing rubber-tired skidders on moderately undulating sites in the Brazilian Amazon increased productivity by 41 percent to 49 percent over CL bulldozer operations. Unplanned, conventional skidding is less efficient and thus more costly due to delays and damage caused in "roaming", or searching for felled stems in an uncharted forest. Using a bulldozer for skidding in a planned RIL operation increased skidding productivity by 5 percent over CL skidding productivity (Barreto et *al.* 1998).

Winkler (1997) found lower RIL skidding productivity at Itacoatiara. However the components of RIL skidding comprised pre-skidding (skid trail opening, winching to skid trail) and skidding to the log deck.

The CL operation only comprised traditional skidding activities, and used a rubber tire skidder

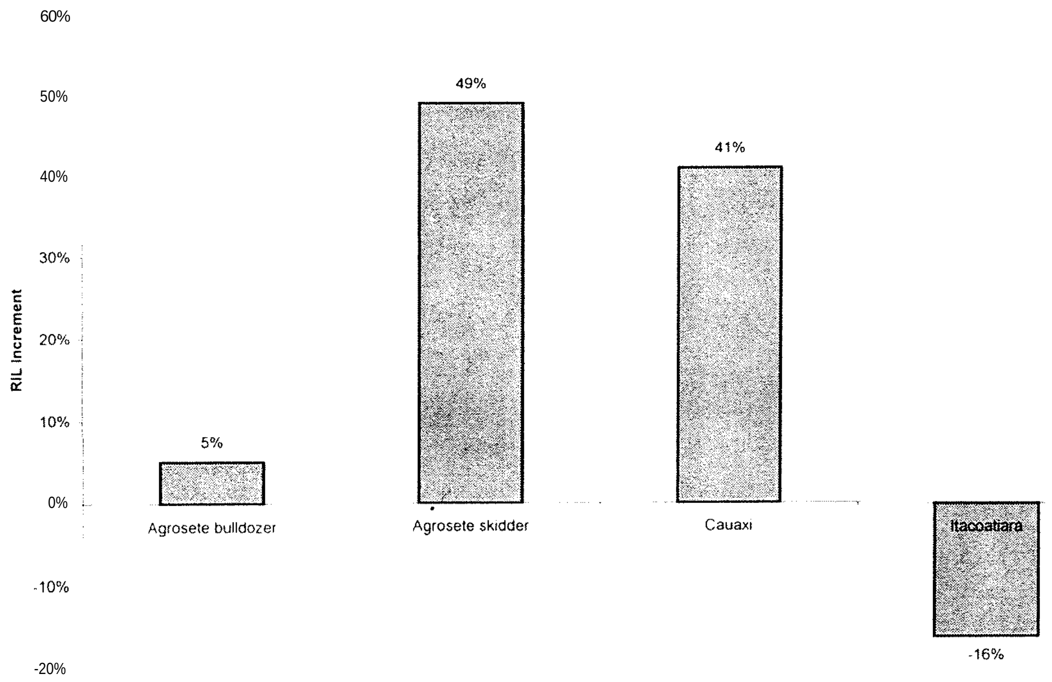

Figure 2. **Incremental productivity of RIL skidding (m^3 h”), computed as (RIL productivity • CL productivity)/CL productivity.**

Cost Comparisons

RIL operations incur costs associated with pre-harvest activities (block layout and line cutting, inventory, vine cutting, data processing and mapmaking) and harvest planning activities (tree marking, road planning, log deck planning and skid trail layout) that are not incurred by CL operations. In addition, RIL requires special training of personnel that incurs costs beyond the on-the-job training received by CL operators. The crux of the matter is whether or not gains in efficiency attributable to planning operations equal or exceed the incremental RIL costs.

RIL Costs’

RIL investments in inventory, planning, vine cutting and infrastructure development up to a year before logging increases the proportional cost of pre-harvest operations (Fig. 3). The incremental pre-harvest costs of RIL are expected to be an important disincentive to RIL adoption by the conventional logging industry (Barreto et *a/.* 1998, Hammond et *al.* 2000, Holmes et *al.* 2000). Inventory, vine cutting and road, log deck and skid trail layout are found to generate the highest incremental costs to RIL. These costs are compounded forward from the time they are incurred to the time of harvest. In general, CL operations do not incur these “advance” costs. However, infrastructure costs associated with the construction of roads and log decks are decreased as a consequence of pre-harvest and harvest planning activities (Barreto et *al.* 1998; Winkler 1997; Holmes et *al.* 2000).

RIL training costs comprise 1 percent to 18 percent of total harvest cost for CL and RIL operations. Training costs vary considerably among the studies, though methods of calculation were not uniform, nor were these data reported by all studies. In Barreto et *al.* (1998), training costs are estimated as an immediate wage increase for RIL trained personnel. In contrast, Holmes et *al.* (2000) amortizes training costs over 5 years of logging operations.

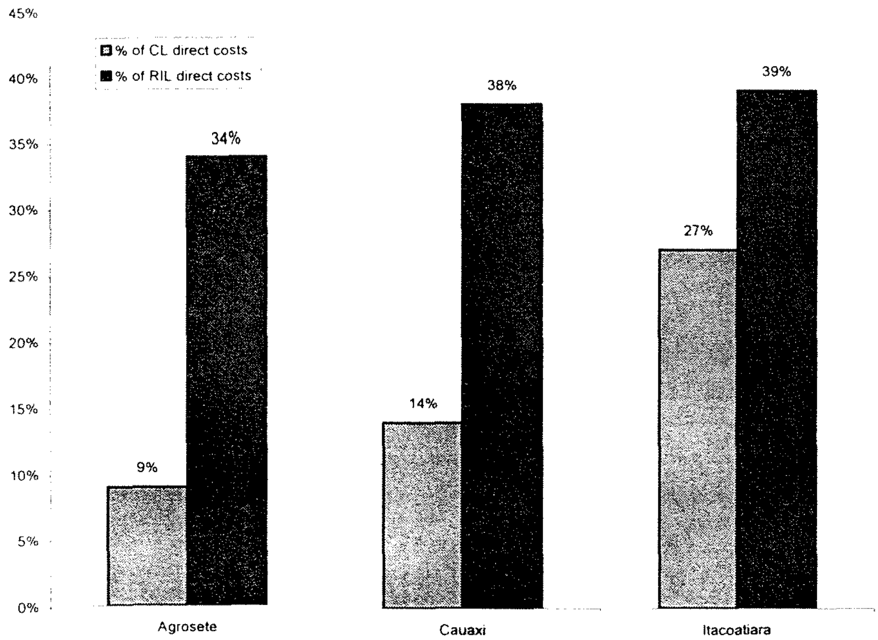

Figure 3. Planning and infrastructure costs as a proportion of direct costs for RIL and CL.

Direct Costs

RIL direct costs[2] (in US$/m³) are 3 percent lower to 34 percent higher than CL direct costs (Fig. 4). Of the three case studies examined, RIL direct costs are lower than CL direct costs only at Fazenda Cauaxi in Paragominas (Holmes et *al.* 2000). At Cauaxi, pre-harvest and harvest planning activities, and the reduction in felling efficiency due to directional felling, resulted in a RIL incremental cost of $1.33/m^3 However, efficiency gains in road construction, log deck construction, skidding and log deck operations resulted in a cost savings of $1.48/m^3. Thus, the gain in efficiency more than offset the RIL incremental costs.

In contrast, Winkler (1997) found that direct costs of RIL were 9 percent higher than CL costs. This may be due, in part, to the fact that harvest intensity on the CL plot was more than 2.5 times greater than on the RIL plot, which would likely decrease per unit direct cost of CL. Also, Winkler (1997) notes that planned changes to the RIL operation would result in RIL costs, that are only 1.5 percent higher than CL costs.[3]

Barreto et *al.* (1998) found that pre-harvest and harvest planning activities increased RIL costs by $1.87/m^3. Gains in operational efficiency, particularly the skidding operation, resulted in a cost reduction of $0.24/m^3, or a cost recovery of 13 percent of the incremental RIL expenditures. Overall, RIL direct costs were 34 percent higher than CL at Fazenda Agrosete.

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[2] Direct costs include planning, vine cutting, infrastructure development, felling, skidding and log deck operations. We exclude transport from deck to mill as not all studies reported this measure

[3] Planned changes include altering crew sizes and equipment used by the felling and skidding crews

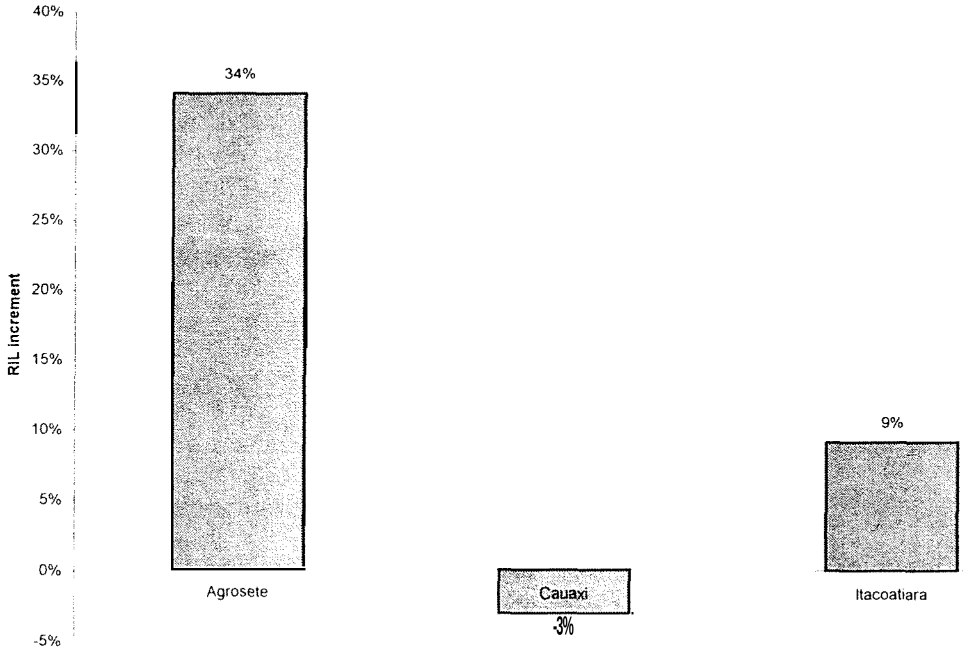

Figure 4. Incremental change in direct costs attributable to RIL ($US/m^3), computed as (RIL cost - CL cost)/CL cost.

Waste Wood Accounting

At Fazenda Cauaxi, CL operations wasted 4.08m^3 ha" due to: (1) high stumps, (2) poor felling technique resulting in split logs, (3) wood wasted in improper bucking, and (4) logs not found by skidding crews. RIL operations wasted 1.32m^3 ha" for these reasons. In addition, logs left unutilised on the log deck amounted to 1.97m^3 per hectare (0.60m^3 ha") for CL (RIL) operations (Holmes et *al.* 2000). Overall, wasted wood represented 24 percent (8 percent) of the recovered volume at Fazenda Cauaxi by CL (RIL) operations (Holmes et *al.* 2000).

At Fazenda Agrosete, CL (RIL) operations wasted 8.83m^3 ha^{-1} (0.40m^3 ha-') in the forest[4]. These amounts represented 26 percent and 1 percent of volumes felled by CL and RIL crews, respectively (Barreto et *al.* 1998).

At Mil Madeireira Itacoatiara, CL (RIL) operations wasted 2.99m^3 ha^{-1} (1.31m^3 ha-'). These amounts represented 9 percent (4 percent) of volumes extracted by CL and RIL crews, respectively.

When waste wood is not accounted for, direct costs appear deceptively lower for CL The Paragominas case studies reported accounting adjustments for costs associated with wood waste, while Itacoatiara did not. Wood waste incurs direct costs associated with felling, bucking, skidding and log deck activities and indirect costs[5] by increasing the effective stumpage price (Holmes et *al.* 2000). It may be expected that waste costs are commonly not accounted for in CL operations, given that inventory and monitoring activities necessary for such accounting are not conducted. Although this asymmetric information effectively biases estimates of returns to logging, the exceptional profitability of timber harvest provides conventional firms the luxury to function inefficiently and to ignore such losses.

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[4] Barreto et al. (1998) and Winkler (1997) do not report the amount of timber left unutilised on log decks.

[5] Indirect costs include stumpage fees (paid on a per hectare basis), field support, maintenance, overhead and other administrative costs

Profitability Comparisons

When direct and indirect waste costs are accounted for, RIL net revenues are 18 percent to 35 percent greater than CL ***net revenues.*** Relative gains in profitability at Agrosete were due to two factors: (1) a greater amount of wood wasted per hectare was reported, and (2) waste adjustments were computed using stumpage and revenue impacts (Barreto 1998). At Cauaxi, waste adjustments were computed using impacts on direct costs and on effective stumpage price. We can only speculate on the impact that waste accounting would have at Itacoatiara. However, accurate waste accounting clearly increases the competitiveness of RIL relative to CL.

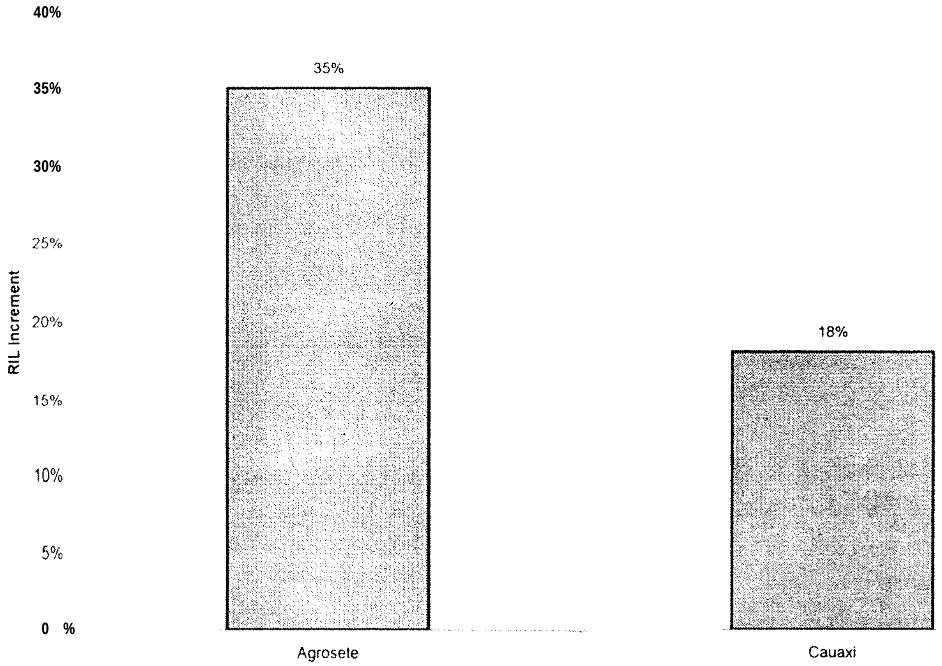

Figure 5. Incremental change in net revenues attributable to RIL ($US\$/m^3$) after accounting for waste related losses, computed as (RIL net revenue - CL net revenue)/CL net revenue.

Tropical timber harvesting of primary forests is highly profitable. CL in Paragominas demonstrates profit margins of 39 percent to 52 percent and RIL demonstrates profit margins of 46 percent to 63 percent [6]. Although profit margins for RIL exceed CL for the studies reporting such measures, highly profitable CL firms face few incentives to alter their operations unless they face dramatic changes in market signals such as increases in stumpage prices or decreases in product prices. In this sense, logging firms may seek a "satisfactory", rather than "maximal", level of profit in initial harvest entries in primary forests.

Discussion and Conclusions

RIL appears competitive with or superior to CL in financial returns to initial harvest entries if wood wasted in the harvesting operation is fully accounted for. If stumpage is treated as a "free good", or if it is under-priced, economic theory states that it will be over-utilized from a social perspective. This appears to be occurring in the areas of the Brazilian Amazon currently experiencing intensive commercial exploitation. Wasted wood incurs direct costs associated with wasted labor and equipment use. However, the major financial impact is related to the increase in effective stumpage

[6] Profit margins were computed as net revenue/gross revenue. Jenkins and Smith (1999) report that the logging and sawmill industry in Par< earned a profit margin of about 33 percent in 1992.

price. Stumpage and timber prices are market signals that reflect economic scarcity. Current market signals (or the lack thereof) d'o not seem to provide incentives to adopt practices that appear immediately more costly. **We recommend that a stumpage and timber price reporting series be instituted in the Brazilian Amazon.** Such a series would benefit landowners and mill-owners by providing publicly shared information about resource values and trends. We expect that this would facilitate better resource planning and provide incentives for more informed and conservative use of timber resources.

Of major import is the lack of standardized data that would permit an understanding of functional relationships between forest types, input and output prices, industrial scale and costs and returns. Development of data to facilitate the estimation of cost and profit functions for the logging and milling industries in the Brazilian Amazon would facilitate effective planning for industrial development by identifying conditions where the application of RIL operations in new markets would be efficient and competitive with more destructive logging practices.

Although this study compares only three case studies, comparative analysis was hampered by the lack of standard protocols used by each study. **We recommend that consideration be given to creation of standard cost accounting categories and methods for data collection.** Only if a standard cost accounting system is developed and applied will meaningful broad-scale comparative analyses be possible.

RIL prescriptions define the pattern and intensity of harvesting and the resulting opportunity costs of RIL relative to CL. When RIL is designed to mimic CL harvesting in terms of harvest level, species, size classes, and spatial distribution, gains in operational efficiency and waste reduction render RIL environmentally and economically superior to CL for initial harvest entries (Barreto et *al.* 1998, Holmes et *al.* 2000). However, when RIL is implemented as part of a forest management prescription, in which areas and stems are set-aside to maintain productivity and ecosystem integrity, the opportunity costs relative to conventional liquidation harvest of all merchantable stems may be too great for RIL to be competitive. For instance, van der Hout (1999) found the cost and damage savings in spatially restricted harvest of "clumped" species under CL were superior to those under a RIL prescription requiring spatially distributed, selective harvest under RIL. Winkler (1997) notes that 1/3 of the RIL forest area was set aside as preservation forest, while no such set-asides were designed under CL. The opportunity costs of foregone merchantable timber in set-asides likely leads to inferior RIL financial competitiveness relative to unconstrained, liquidation harvest of merchantable stems under CL, despite gains in operational and resource use efficiency. Such were the conclusions of RIL-CL studies in Sabah, Malaysia (Tay 1999, Pinard et a/. 2000), in which RIL was found financially inferior due in large part to foregone timber excluded from RIL due to environmental harvesting restrictions. **Economic incentives appear necessary to promote the adoption of RIL as part of a long-term forest management system.**

Tenure security and forestland scarcity determine estimates of efficiency and profitability for loggers and the relative importance of incremental gains in resource use efficiency that may be derived from RIL implementation. It is expected that important benefits of damage mitigation will be derived in future harvest entries, given greater conservation of future crop trees and reduced environmental disturbance under RIL. **Tenure security is critical to the inclusion of future harvest returns in management profitability analyses and to expectations of financial benefit for careful management and conservation relative to more destructive practices.** Moreover, resource scarcity and harvests constrained to a fixed resource base provide greater relevance for issues of resource use and timber recovery efficiency. Without land availability constraints and clear market signals of scarcity, loggers will not likely be drawn to the marginal increments in resource use efficiency that may be gained under RIL. In a broader landscape without resource constraints, the opportunity costs of more careful RIL management relative to maximizing turnover and throughput of timber may be too high for conventional firms to change their logging behavior.

References

Barreto, P., P. Amaral, E. Vidal, and C. Uhl. 1998. Costs and benefits of forest management for timber production in eastern Amazônia. Forest Ecology and Management 108:9-26.

Boscolo, M., J. Buongiorno, and T. Panayotou. 1997. Simulating options for carbon sequestration through improved management of a lowland tropical rainforest. Harvard institute for international Development, Cambridge, MA.

Boxman, O., N.R. de Graaf, J. Hendrison, W.B.J. Jonkers, R.L.H. Poels, P. Schmidt, and R.T.L. Sang. 1985. Towards sustained timber production from tropical rain forests in Suriname. Netherlands Journal of Agricultural Science 33:125-132.

Bryant, D., D. Nielsen, and L. Tangley. 1997. The last frontier forests: ecosystems and economies on the edge. World Resources Institute, Washington DC. 80 p.

Dykstra, D. P. and R. Heinrich. 1996. *FAO Model Code of Forest Harvesting Practice,* FAO, Rome

Frumhoff, P.C. and E.C. Losos. 1998. Setting priorities for conserving biological diversity in tropical timber production forests. Union of Concerned Scientists. Center for Tropical Forest Science, Smithsonian Institution, Washington, D.C. 14 p

Holmes, T.P., G.M. Blate, J.C. Zweede, R. Perreira Jr., P. Barreto, F. Boltz, and R. Bauch. 2000. Financial costs and benefifs of reduced-impact logging relative to conventional logging in the eastern Amazon. Tropical Forest Foundation, Washington D.C. 48 p

Hout, P. van der. 1999. Reduced impact logging in the tropical rain forest of Guyana : Ecological, economic, and silvicultural consequences. Tropenbos-Guyana series 6. Tropenbos-Guyana Programme, Georgetown, Guyana. 355 p.

ITTO. 1996. Annual review and assessment of the world tropical timber situation. Yokohama, Japan.(May 5, 1998).

ITTO. 1999. Annual Review and Assessment of the World Timber Situation 1999. Document GI-7199. ITTO, Yokohama. 55p. (August 25, 2000).

Jenkins, M. B. and E. T. Smith. 1999. The business of sustainable forestry: strategies for an industry in transition. island Press, Washington, D.C. 356 p.

Johns, J.S., P. Barreto and C. Uhl. 1996. Logging damage during planned and unplanned logging operations in the eastern Amazon. Forest Ecology and Management 89:59-77.

Johnson, N. and B. Cabarle. 1993. Surviving the cut: natural forest management in the humid tropics. World Resources Institute, Washington, DC. 71 p.

Nepstad, D.C., A. Verissimo, A. Alencar, C. Nobre, E. Lima, P. Lefebvre, P. Schlesinger, C. Potter, P. Moutinho, E. Mendoza, M. Cochrane, and V. Brooks. 1999. Large-scale impoverishment of Amazonian forests by logging and fire. Nature 398:505-508.

Pinard, M.A., F.E. Putz, and J. Tay. 2000. Lessons learned from the implementation of reduced-impact logging in hilly terrain in Sabah, Malaysia. Int. For. Rev. 2:33-39.

Pinard, M.A. and F.E. Putz. 1996. Retaining forest biomass by reducing logging damage. Biotropica 28:278-295.

Precious Woods, Ltd. 1997. Management plan for sustained use of the forests of Mil Madeireira ltacoatiara Ltda. Draft version, February 18, 1997. Itacoatiara, Amazonas, Brazil.

Putz, F. E. and M. A. Pinard. 1993. Reduced-impact logging as a carbon-offset method. Conservation Biology 7: 755-759.

Tay, J. 1999. Economic assessment of reduced impact logging in Sabah, Malaysia. Ph.D. dissertation. University of Wales, Bangor, UK. 161 p.

Uhl, C., P. Barreto, A. Verissimo, E. Vidal, P. Amaral, A.C. Barros, C. Souja Jr., J. Johns, and J. Gerwing. 1997. Natural resource management in the Brazilian Amazon: An integrated research approach. Bioscience 47:160-168.

Varian, H. 1984. Microeconomic analysis. W. W. Norton & Company, New York

Williams, M. (1989). Americans and their forests: a historical geography. Cambridge University Press, New York.

Winkler, N. 1997. Environmentally sound forest harvesting: Testing the applicability of the FAO Model Code in the Amazon in Brazil. Forest Harvesting Case Study 8. FAO, Rome. 78 p.