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No.1

FORESTRY DEPARTMENT

REDUCED IMPACT LOGGING IN TROPICAL FORESTS

Literature synthesis, analysis and prototype statistical framework

November 2004

This paper is one of a series of working papers on forest harvesting and engineering produced by FAO's Forest Harvesting and Engineering Programme. The purpose of these working documents is to provide early information on on-going activities and programmes – and to stimulate discussion.

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FOREST HARVESTING AND ENGINEERING PROGRAMME

REDUCED IMPACT LOGGING IN TROPICAL FORESTS

Literature synthesis, analysis and prototype statistical framework

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 2004

FOREWORD

Forests provide multiple products and services, with the potential to contribute to employment and income generation. It is important for countries to increase the value and sustainable use of forest goods and services in harmony with national resource conservation and environmental protection goals. This calls for the use of environmentally sound harvesting, engineering and processing methods and appropriate trade and marketing strategies.

The use of reduced impact logging (RIL) is becoming more and more widespread in tropical regions, and there is an urgent need for careful assessment of its impact. In addition, the costs of each logging phase and the costs for road construction or other development are not well documented or modelled for application to general conditions.

For these reasons, governments are now imposing stricter regulations on forest harvesting and wood markets, and are insisting on responsible harvesting practices as can be seen, for example, in the growth of demand for certified wood products. Given the political and market demands for change, the nature of RIL needs to be more clearly defined. Some important questions must be addressed, such as: What have harvesting studies, so far carried out, been telling us and, perhaps even more important, what have these studies not told us? What should researchers do to continue promoting or not promoting reduced impact logging? Finally, does RIL cost or does it pay?

To address all these questions, the present Working Paper No. 1 of the Forest Products Service has been prepared, based on a review of articles dealing with logging intensities, logging cycles and waste, residual stand and site damage and the economics of forest operations. The initial review on logging impacts, conducted in 1997 for the FAO Global Fibre Supply Model (Pulkki, 1997) was updated in 2000, and again in 2003. It now contains over 300 entries.

In Appendix 1 of the Working Paper, a variety of definitions of RIL are collected. Appendix 2 includes tabular summaries on location, descriptive information, logging intensity and cycle, residual density and utilization, site damage, economic aspects and the source of the information. A summary of each report reviewed can be found in Appendix 3.

There are still serious data deficiencies with regard to planning and inventory, and there is a serious lack of standardization in data collection. Therefore, readers are invited to send their inputs to Forest-Harvesting@fao.org and participate in the future development of a forest harvesting information system. It is hoped that this study will contribute to the ongoing worldwide dialogue on reduced impact logging.

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1. INTRODUCTION

There has been an increasing interest in reduced impact logging (RIL), particularly in tropical forests over the last decade. A number of developments have led to the concept of RIL: a political focus on sustainable development at the highest levels, a general consensus about the necessity to manage forests more sustainably, and recognition that better technology is now available to monitor harvesting practices and forest conditions. There is a general desire to reduce negative environmental impacts all the way down to the operational level. It is also generally recognized that many conventional logging systems will not continue to produce sustainable yields of the same volume and/or quality of timber, particularly in non-coniferous tropical forests (NCTF). For these reasons governments are now imposing stricter regulations on forest harvesting and wood markets, and demanding more responsible harvesting practices. The demand for certified wood products has continued to grow. Given the political and market demand for change, there is a commensurate desire to further articulate the nature of RIL.

The objectives of the paper are to:

- Provide a definition and characteristics of RIL;
- Summarize a review of existing literature on logging intensities, residual stand and site damage, and wood waste associated with conventional logging (CL) and RIL;
- Present basic terminology related to logging methodologies;
- Provide a tabular summary of bibliographic material by country and source and;
- Generate an annotated bibliography covering the existing literature on logging systems in NCTF.

2. REDUCED IMPACT LOGGING (RIL)

In most cases, non-coniferous tropical forests (NCTF) are managed under polycyclic silvicultural systems. Unfortunately, selective cutting (i.e., high grading) and not `true' selection cutting is most often practiced. According to Johns (1992), the most effective management of most tropical forests entails the protection and encouragement of advanced growth in optimally sized canopy gaps created during logging, with planting of gaps where no advanced growth exists. Critical for the sustained management of these forests is the implementation of reduced impact logging (RIL) techniques (Nicholson 1965, Putz 1994, ISTF 1995, Marsh *et al.* 1996, Weidelt 1996, Stokes *et al.* 1997). Palmer and Synnott (1992) state; "*while the merits of various forest management systems are being debated, tropical silviculturalists are of one voice in advocating the use of RIL techniques*."

Various authors (Armstrong and Inglis 2000; Dykstra and Heinrich (1996), Elias 2000, Van der Hout 1999, Reid and Rice 1997, Ruslim *et al.* 1999, Sist *et al.* 1998, Sist 2000, Vanuatu Department of Forests 1999, Webb 1997) have proposed definitions or aspects of reduced impact logging. They are fully described in Appendix 1. Summarizing the work of these authors, RIL is defined as:

`Intensively planned and carefully controlled implementation of harvesting operations to minimise the impact on forest stands and soils, usually in individual tree selection cutting.'

RIL is generally characterized by having stand entries only at a predetermined cutting cycle, which generally should be no shorter than 20 years. No more than one-third of the basal area should be removed at one entry and a pre-harvest operational inventory is strongly recommended. Access road construction should be done well in advance of harvesting, and climber cutting, if required, should be done up to two years before harvest. Planning should consist of tree marking, location mapping and planned felling direction, and this should be linked with the layout of a minimal number of extraction trails. Once the logs are removed, they should be placed on landings of minimal size. The logging operations should only be conducted under favourable conditions (e.g. when soils are dry). The forest workers and supervisors should be well trained so that they can ensure minimal negative impacts on the site; maximum utilization of the trees felled; minimum damage to residual trees and advanced regeneration; and rehabilitation of negative impacts that may have occurred on the site. Finally they should be well qualified to conduct a post-harvest assessment.

RIL generally includes, but is not limited to, the following:

- Pre-harvest inventory and mapping of individual crop trees;
- Pre-harvest planning of roads, skid trails, and landings to provide access to the harvest area and to the individual trees scheduled for harvest while minimizing soil disturbance and protecting streams and waterways with appropriate crossings;
- Pre-harvest liana cutting in areas where lianas inter-connect tree crowns;
- The use of appropriate felling and bucking techniques, including controlled felling;
- Construction of roads, landings and skid trails that adhere to engineering and environmental design guidelines;
- Winching of logs to planned skid trails and ensuring that skidding machines remain on the skid trails at all times;

- Conducting a post harvest assessment in order to provide feedback to the concession holder and logging crews and to evaluate the degree to which RIL guidelines were successfully applied.

RIL techniques are not difficult to implement. At the operational scale, the savings due to more efficient operations (when compared to conventional logging practices) will generally offset any additional costs in planning, layout and control, and make it at least cost neutral (Andel 1978, Mattsson-Marn and Jonkers 1981, Tabudar 1984, DeBonis 1986, Hendrison 1989, Pinard *et al.* 1995, Sayer *et al.* 1995, Bruenig 1996, Moura-Costa 1997). However, the implementation of RIL has been sporadic in practice and sustainable management of tropical forests is rare (FAO 1989a, Buenaflor 1990, Jonsson and Lindgren 1990, Tuomela *et al.* 1996). Where RIL techniques are not implemented, the volumes extracted in second and third cuts will be much reduced from those of the first cut. This is reflected in the logging intensities from natural (previously unlogged) and semi-natural (previously logged) forests (FAO 1997).

3. SUMMARY OF EXISTING LITERATURE

A total of 345 studies and articles on reduced impact logging or conventional logging conducted in closed broad-leaved tropical forests and published since 1950 were reviewed and classified in this paper. The majority of these studies were published in the last decade, but were not presented according to a standardized system. In the 1970s, the number of publications on conventional logging (CL) increased rapidly whereas RIL was covered in only few publications prior to 1980.

3.1 Logging Intensity and Stand & Site Damage

Minimizing the damage to the residual trees and advance regeneration during logging is essential for the success of all polycyclic silvicultural systems. In practice though, very little consideration is given to this. Referring to Appendix 2, it is quite apparent that damage to the residual stand in conventional logging operations is excessive. Damage to residual trees ranges from 33-70% in areas with higher (e.g. >30 m^3/ha) logging intensities (Nicholson 1958b, Fox 1968, Burgess 1971, Tinal and Palenewen 1978, Abdulhadi *et al*. 1981, Masson 1983, Yeom 1984, Korsgaard 1985, Ayres and Johns 1987, Uhl and Viera 1989, Pinard *et al*. 1995, Dykstra *et al*. 1996, Elias 1996, Greiser-Johns 1996, Berthalt and Sist 1997). In areas with lower logging intensities (e.g. in Africa with removal of 1-2 trees/ha), residual stand damage generally ranges from 10-20% (Ola-Adams 1987, White 1994, Cordero and Howard 1996, Scharpenberg 1997). However, tree damage does not increase in direct proportion to felling intensity (Verissimo *et al*. 1987). Levels of damage typical of conventional logging operations are unacceptably high.

Implementation of RIL has resulted in the reduction of residual tree damage from 50-200% (Mattsson-Marn and Jonkers 1981, Bote 1983, Reyes 1983, Malvas 1987b, Buenaflor 1989, Hendrison 1989, Johns *et al*. 1996, Berthault and Sist 1997, Moura-Costa 1997). With the implementation of RIL techniques, logging intensities can be significantly increased and still result in less damage to residuals. For example, Buenaflor (1989) found 67% of residuals damaged in uncontrolled logging with 23 m^3/ha removed, while in a controlled logging area 22% of residuals were damaged with 32 m^3/ha removed.

Some damage will always occur with the felling of trees and it can be expected that with careful felling approximately 200 m^2 of forest area will be damaged with each felled tree (Weidelt 1996). Therefore, there is a maximum logging intensity threshold beyond which maintaining stand integrity is difficult in selection cutting. For example, Watanabe (1992) gives this threshold as 30% of stand basal area. Skid trails are also required, but skidding damage can be minimized by planning the trails, utilizing the optimum trail spacing, keeping the trails straight, directional felling of trees on an angle towards trails, keeping the skidders on the trails, utilizing the winch more, limiting skidding operations during wet periods, using the correct size of skidder (i.e. not too large and not too small), skidding log lengths, and utilizing bumper trees where required. The skill and work ethic of both fellers and skidder operators are also critical in minimizing damage.

As with residual stand damage, site impacts in conventional logging of NCTF are excessive. In high logging intensity and uncontrolled logging areas, 30-75% of the area can be serious impacted with roads, tractor trails, landings or just otherwise bulldozed (e.g. when gathering logs with the blade) (Chai 1975, Kartawinata 1978, Neil 1984, DeBonis 1986, Buenaflor 1989, Bruenig 1996, Dykstra *et al*. 1996, van der Hout 1999). However, typically in higher logging intensity areas (e.g. 30-50 m^3/ha), 10-25% of the area is impacted by roads, skid trails and landings

(Nicholson 1958a, Borhan *et al.* 1987, FAO 1989b, Hendrison 1989, Uhl and Viera 1989, Malmer and Grip 1990, Sim and Nykvist 1991, Verissimo *et al.* 1992, Cannon *et al.* 1994, Ohn *et al.* 1996, Winkler 1997, van der Hout 1999). In lower logging intensity areas the soil disturbance is from 6-13% of the area (Bullock 1980, Uhl *et al.* 1991, White 1994, Agyeman *et al.* 1995, Scharpenberg 1997). Bruenig (1996) states that with excessive roading and skidding, and thus excessive compaction and erosion, felling cycles of 25-50 years are not sustainable and 60-100 years is more realistic. Tropical soils are also highly susceptible to degradation when physically disturbed, and exposed to the sun and/or the direct impact of heavy tropical rains (Poore and Sayer 1987).

3.2 Logging Intensity and Wood Waste

Better wood utilization efficiency in both harvesting and mill processing can greatly enhance the sustainability of the tropical timber industry (Noack 1995). The extent of logging waste reported in the literature generally ranges from 30% (Silitonga 1987, Bhargava and Kugan 1988, Gerwing *et al.* 1996, Muladi 1996, Scharpenberg 1997) to 50% (Virtucio and Torres 1978, Dykstra 1992, Noack 1995) of the extracted log volume.

Through a review of tropical countries Dykstra (1992) estimated felling recovery rates to be 54% in Africa, 46% in Asia/Pacific, 56% in Latin America and the Caribbean, and 50% on average for all tropical areas. A similar study by Noack (1995) in Ghana, Cameroon East Kalimantan and Sarawak found that on average 53.5% of the tree was extracted; of the remaining volume 4.6% was stump, 5.2% buttress, 10.4% stem off-cuts and 26.3% were parts of the crown with diameter >20 cm. Variations in felling recovery rates reported in the literature are due to operational efficiency and skill of workers, available markets for lower grade logs, and differences in the definition of merchantable wood.

One source of logging waste is felled and bucked trees which are not found during the skidding operation. For example, Mattsson-Marn and Jonkers (1981) found that 11 m^3/ha (20% of extracted volume) of logs could not be found by the skidder in current operations. In a planned harvesting block the volume lost was reduced by 100% to 5.5 m^3/ha. Gerwing *et al.* (1996) found that 6.6 m^3/ha (22% of extracted volume) of usable timber was felled but never skidded. A similar result was found by Uhl *et al.* (1997) who reported 7 m^3/ha (20% of extracted volume) felled and never recovered. Through RIL techniques, and mapping of felled trees and felling directions the loss of logs can more or less be eliminated.

Logging wastes also develop due to poor work methods, and felling and bucking techniques which result in the splitting and breaking of felled trees (Hendrison 1989). High stumps, felling above the buttress and topping at too large a diameter also result in excessive waste (Balachandra 1988, Gerwing *et al.* 1996). Brotoisworo (1991) attributes the low skill of workers to part of the 35-40% of the logging waste he found. The estimated volume of waste due to felling and bucking losses is about 6.5-8.5% of the utilizable stem volume (FAO 1989a, Winkler 1997). In addition to volume loss due to poor felling and bucking techniques there can be significant value losses.

A problem outlined by Quirós *et al.* (1997) is that loggers are paid based on the volume removed. Therefore, they only take out the best and largest logs, resulting in 20-25% of the cut volume not being extracted due to felling damage or poor quality. In many cases the logging waste left is suitable for supplying local markets through small-scale sawmilling. Hendrison (1989) also found that serious wood damage and quality loss can occur during positioning and collecting (bunching) logs with the blade of a skidder.

Logger training is a key factor in reducing logging waste and value loss. Uhl *et al.* (1997) found that trained loggers were able to achieve a 300% reduction in waste associated with felling a bucking, while Winkler (1997) found a 120% reduction. DeBonis (1986) also found that a 15-30% increase in wood volume at the mill could be realized through proper felling and bucking techniques. Cross-cutting training programs have also shown that log values can be increased by 10-50% (Dykstra and Heinrich 1996).

Wood volume losses or waste also occur at roadside landings, export ports, mill yards and in manufacturing itself. For example, Kilkki (1992) found in a study in Papua New Guinea that 10-35% of the export volume was left at the harbour as not fulfilling export grade rules. Bethel (1984) states that overall product yield from a tree can be as low as 10 to 20%, and typically averages no more than 30%. This is supported by Buenaflor and Karunatilleke (1992) who state that 70% of the wood being logged from natural forests is wasted owing to both poor harvesting and mill processing, and the non-availability of markets for all wood.

Mill process yields have been reported to be as low as 33% of delivered log volume (Barros and Uhl 1995, Gerwing *et al.* 1996, Uhl *et al.* 1997). Noack (1995) reported sawmill lumber recovery factors (LRF) ranging from 36% to 57%. In other reports reviewed, the LRF reported varied from 45-55% (Silitonga 1987, Kilkki 1992, Verissimo *et al.* 1995, Muladi 1996). When sawing large diameter tropical hardwood logs the LRF should be at least 50% (Uhl *et al.* 1997), and yields of 56-68% should generally be expected (Niedermaier 1984).

3.3 The Economics of RIL

While the benefits of RIL are widely acknowledged, the incremental costs of adopting RIL practices are commonly viewed as a principal impediment to their adoption by loggers. RIL requires increased investments in training and planning. This in turn results in a more efficient logging operation and optimal use of logging equipment (e.g. reduced skidding distances and improved log recovery). The development and application of the CELOS system in Suriname showed that planned logging could be cheaper than conventional logging due to reduced skidding costs (Hendrison 1990). Barreto *et al.* (1998), using a modification of the CELOS system developed by IMAZON, confirmed this result. However, another study in Brazil, near Manaus in the state of Amazonas, found that environmentally sound forest harvesting was moderately more expensive than the traditional logging system (Winkler 1997). This may have been due to a modified skidding system which utilized both pre-skidding and skidding phases. In Guyana, van der Hout (1999), showed that the cost of RIL was almost identical to the cost of conventional logging.

When harvesting intensity is considered in the economic analysis, increased initial costs of RIL may be recovered in decreased machine and labour costs and decreased logging waste (Uhl *et al.* 1997, Holmes *et al.* 2002). Johns *et al.* (1996) provide evidence of a net increase in profits of 1% for RIL in Paragominas, Brazil when harvest efficiency is considered. However, in areas with high biodiversity values or steep slopes, the balance of costs and benefits may be different due to the large quantity of foregone timber. High wages relative to machine costs may also contribute to higher costs for RIL compared with conventional logging. From the viewpoint of the forest owner, RIL may be advantageous, as reduced damage to regeneration will translate into a higher yield in the second cycle of logging. Whether cost savings demonstrated in relatively small experimental settings would be achieved when RIL is applied to large-scale operations remains to be seen. It should also be realised that applying RIL changes the distribution of costs and benefits among stakeholders.

4. CONCLUSION

Throughout all of the literature there is consensus that the vast majority of logging in NCTF continues to be inefficient, wasteful and excessively destructive to both residual trees and the site itself. In some cases (e.g. Nicholson 1979) there is evidence that logging has become more destructive with increased reliance on high horsepower equipment than on technical competence. The benefits and techniques of RIL are well documented in all parts of the tropics, but full implementation of RIL is rare. Logging as currently practiced in NCTF is non-sustainable and this is reflected in the GFSS database with considerable reductions in veneer log and saw log logging intensity in the second cutting cycle. It is expected that if current logging practices continue the third cut will be still lower or even non-existent.

On the other hand, with the implementation of RIL logging techniques and silvicultural systems such as CELOS and CATIE, many studies indicate there will be cost savings due to more efficient operations. As experience grows with the implementation of RIL it is expected that at least a cost neutral situation will occur. The major benefit, however, will be stable future yields and sustainable forest management operations. This will result in future income, which otherwise will be lost.

Actual logging intensities vary considerably between regions, countries and even within countries (e.g. Appendix 2). The cutting cycle also varies considerably, but many reports are suggesting 40 years. This allows for the ingrowth of trees into the next higher diameter class; for example, from the 40-60 cm into the 60-80 cm dbh class (average diameter growth of 0.5 cm/year). Based on the literature, and with the implementation of RIL and appropriate silvicultural treatments, it is felt that an average logging intensity of 20 m^3/ha on a 40-year cycle is possible in closed NCTF in Africa, and Latin America and the Caribbean. Sundberg (1978) gives a logging intensity of 20 m^3/ha as the economic threshold, below which the relative logging cost increases exponentially. This economic threshold becomes very important with the extraction of lower value logs and species, and with the implementation of RIL. In the dipterocarp forests of Asia/Oceania an average logging intensity of 40 m^3/ha on a 40-year cycle should be easily achievable. In must be remembered though, that these are conservative and general averages, and the actual logging intensity and cutting cycle will depend on the condition of the forest itself and the species involved. In addition to the full implementation of RIL, a wider range of species must be commercialized and the utilization of felled trees improved.

APPENDICES

APPENDIX 1 TERMINOLOGY USED IN TIMBER HARVESTING AND POST HARVEST OPERATIONS

Aboveground biomass
- Aboveground portion of a tree, excluding the root system

Acceptable growing stock
- Trees of commercial species that meet specific quality standards

Access
- Means of gaining entry to timber on a tract or logging chance.

Aerial logging
- Yarding system employing aerial lift of logs, such as balloons or helicopters.

Afforestation
- Establishment of forest crops by artificial methods, such as planting or sowing on land where trees have never grown.

Age
-*Of a tree - the* time elapsed since the germination of the seed, or the budding of the sprout or cutting from which the tree developed.

-*Of a forest* - Mean age of the trees comprising a forest, crop, or stand. In forests, the mean age of dominant (and sometimes co-dominant) trees is taken. The plantation age is generally taken from the year the plantation was begun, without adding the age of the nursery stock.

Age Class
-One of the intervals, commonly 10 or 20 years, into which the age range of tree crops is divided for classification or use. Also pertains to the trees included in such an interval.

All-aged
-Forest or stand containing trees of almost all age classes up to and including trees of harvestable age.

Allowable cut
-Volume of timber that may be harvested during a given period to maintain sustained production.

Allowable-cut effect
-Allocation of anticipated future forest timber yields to the present allowable cut; this is employed to increase current harvest levels (especially when constrained by even flow) by spreading anticipated future growth over all the years in the rotation.

Anchor cable
-Line used to tie down a yarder to prevent tipping on a heavy pull.

Anchor log
-Wooden, concrete, or metal bar buried in the earth to hold a guy rope.

Annual allowable harvest
-Quantity of timber scheduled to be removed from a particular management unit in 1 year.

Annual growth
-Average annual increase in the biomass of growing-stock trees of a specified area.

Appraised price
-Price of a particular timber sale based on the estimate of the timber's actual market value.

Area regulation
-Method of controlling the annual or periodic acreage harvested from a forest, despite fluctuations in fibre-yield volumes.

Artificial regeneration

-Renewal of the forest by planting or direct seeding; establishing a new stand of trees by planting seeds or seedlings by hand or machine.

Aspect

-Compass direction to which a slope faces.

Average yarding (skidding) distance

-Total yarding (skidding) distance for all turns divided by total number of turns for a particular setting.

Back cut

-Final cut in felling a tree. This is usually made on the opposite side of the direction of fall.

Back line

-Boundary line marked by blazed or painted trees indicating the cutting area.

Bank

-Logs cut or skidded above the required daily production and held in reserve.

Barber chair

-High slab-like splint, resembling a chair back, left standing on a stump above the undercut as a result of faulty felling or heavy lean of the tree.

Bardon hook

-Hook used with wire rope slings for gripping trees or logs to be skidded.

-A type of choker hook.

Bark beetle

-Small, cylindrical beetle of the family *Scolytidae*, the adult of which bores into and beneath the bark of various trees for the purpose of egg laying.

Bark residue

-Refers to the bark removed from a log and also to portions of wood and foreign matter such as sand, grit, or stones that may be imbedded in the bark.

Basal area

-Cross sectional area of a tree, measured at breast height (1.3 m). Used as a method of measuring the volume of timber in a given stand.

Basal area factor

-Number of units of basal area per acre (or per hectare) represented by each tree.

Bearing tree

-Tree marked to identify the nearby location of a survey corner. It is also known as a witness tree.

Bed

-To level and buffer the ground along the line on which a tree is to be felled to minimize shattering of the timber.

Bench mark

-Survey reference point, used to signify a starting point.

Bind

-To get a saw stuck when felling or bucking a tree and the sides of the cut pinch in; wedges are used to alleviate the situation.

Binder

-Chain or wire rope used to bind logs.

-Chain or cable used to secure logs on a truck.

Biodiversity (biological diversity):

-The diversity of plants, animals, and other living organisms in all their forms and levels of organization, including genes, species, ecosystems, and the evolutionary and functional processes that link them.

Biomass

-Total woody material in a forest. This refers to both merchantable material and material left following a logging operation.

-In the broad sense, all of the organic material on a given area; in the narrow sense, flammable vegetation to be used for fuel in a combustion system.

- The dry weight of all organic matter in a given ecosystem. It also refers to plant material that can be burned as fuel.

Biomass harvesting

-Harvesting of all material including limbs, tops, and unmerchantable stem and stumps, usually for wood energy.

Blaze

-To permanently mark trees, indicating those to be cut or the course of a boundary, road, or trail.

Bole

-Tree stem that has roughly grown to a substantial thickness, capable of yielding sawn timber, veneer logs, or large poles.

Boring

-Starting a cut in the centre of a log using the tip of the saw blade. Also known as a plunge cut.

Brand

-Log mark used to identify logs. Usually applied in the log yard at the sawmill site.

Broadcast burn

-Controlled fire used as a silvicultural treatment to burn a designated area within well-defined boundaries for the purpose of reducing fuel hazards.

Brush

-Growth of small trees and shrubs.

Brush cut/out

-To clear away brush from a trail, survey line, or around a tree before working.

Buck

-To saw felled trees into shorter lengths.

Buffer strip or buffer zone

-Strip of uncut timber left between cutting units or adjacent to another resource. Also known as a green strip, leave strip, or streamside management zone.

-Land that blocks or absorbs unwanted impacts of forestry activities

Bulk density

-Measure of weight per unit of volume of a material; generally serves as an indicator of the specific gravity of wood.

Bulldozer

-Steel blade mounted across the front of a standard crawler tractor that can be raised and lowered but cannot be angled to one side or the other; therefore all pushing is straight forward.

Butt

-Base of a tree.

-Large end of a log.

Butt cut
-First log cut above the stump.

Butt off
-To cut off a piece of a log because of a defect.
-To square the end of a log.

Buttress
-Ridge of wood that develops in the angle between a lateral root and the butt of a tree, which may extend up the stem to a considerable height.

Cable
-Wire rope used for lines in yarding systems.

Cable logging
-Yarding system employing winches in a fixed position.

Cable yarding
-Taking logs from the stump area to a landing using an overhead system of winch-driven cables to which logs are attached with chokers.

Canopy
-More or less continuous cover of branches and foliage formed collectively by adjacent tree crowns.

Capital
-Plant, equipment, and related facilities used to produce a flow of goods and services.

Cash flow
-Difference between cash receipts and cash, expenditures over a given time.

Chain saw
-Saw that is powered by a gasoline, hydraulic, or electric motor; cutting elements are on an endless chain similar to a bicycle chain.

Chemical thinning
-Any thinning in which the unwanted trees are killed by chemical poisoning; band or frill girdling may be done at the same time. (See silviculture)

Choked
-Condition in which a log is attached to a skidding unit by means of a wire rope or chain choker.

Choker
-Short length of flexible wire rope or chain that forms a noose around the end of a log to be skidded and is attached to the skidding vehicle or to the butt rigging in a wire rope logging system.

Choker hooks
-Fastener on the end of a choker that forms the noose.

Choker man
-Person in a logging operation who places the choker around the log to be hauled to the landing.

Clear-cutting
- A harvesting and regeneration technique that removes the entire tree, regardless of size, on an area in one operation. Clear-cutting produces an even-aged forest stand.

Climax forest
-Plant community dominated by trees representing the culminating stage of natural succession for that specific locality and environment.
-Stage of forest development that is relatively stable and self perpetuating.

Climax species
: -Plant species that will remain essentially unchanged in terms of species composition for as long as the site remains undisturbed. (See also Shade tolerant species)

Clinometer
: -Hand-held instrument used by foresters to measure vertical angles. Such angles, when correlated with specific distances, indicate the height of standing trees.

Co-dominants
: -Trees with crowns forming the upper level of the forest canopy; these trees receive full light from above but comparatively little from the sides, and their medium-sized crowns are usually more or less crowded on the sides.
: -Species in a mixed forest that are equally numerous and vigorous.

Commercial thinning
: -Partial harvesting of a stand of trees for economic gains from the harvested trees and to accelerate the growth of the trees left standing.

Compartment
: -Forest management subdivision or block of land, usually of continuous land ownership.

Competition
: -Struggle among trees and other vegetation, generally for limited nutrients, light, and water present on a site. Competition can cause reduced tree growth. Severe competition in very dense stands may cause stand stagnation.

Complete tree harvesting
: -Harvesting of a complete tree, including the roots.

Conservation
: -Protection, improvement, and wise use of natural resources according to principles that will assure utilization of the resource to obtain the highest economic and/or social benefits.

Continuous forest inventory
: -Timber sampling system that provides for periodic re-measurement of specific stands or plots of individual trees; this shows status and periodic change over time for the forest as a whole and major sub-divisions therein.

Contour felling
: -Timber felled parallel to ground contour line.

Contract logging
: -Operator undertaking all or part of the logging operation for a company.
: -Independent logger who logs standing timber according to the terms of a contract.

Contractor
: -Person who has a contract to do all or any part of a logging job.

Controlled burning
: -Use of fire to destroy logging debris, reduce build-ups of dead and fallen timber that pose wildfire hazards, control tree diseases, and clear land. Other functions of a controlled burn include clearing a buffer strip in the path of a wildfire.

Conventional forest products
: -All commercial round wood products except fuel wood.

Cover Type
: -Category of forest based on its mixes of species

Coppice
: -In silviculture, a tree cutting method in which renewal of a newly cutover area depends primarily on vegetative reproduction like sprouting.

Coppice regeneration

-Ability of certain hardwood species to regenerate by producing many new shoots from a cut stump.

Corduroy

-To build a road by cross-laying it with saplings or small poles to act as a firm surface for hauling or skidding logs from the cutting area to the landing.

Cost-Benefit ratio

-Ratio obtained by dividing the anticipated benefits of a project by its anticipated costs. Either gross or net benefits may be used as the numerator.

Cost of capital

-The investment required to create and maintain productive capital.

Cover type

-Category of forest defined primarily by its vegetative composition and/or locality factors.

-Category of forest, based on its mixes of species

Creaming

-Logging operation where only the best trees in the stand are cut.

Crop tree

-Any tree forming or selected to form a component of the final crop. The tree is usually selected when the stand or plantation is young.

Cross cut

-Wood cut across the grain.

Crown

-Upper part of a tree, including the branch system and foliage.

Crown class

-Class into which the trees forming the crop or stand may be divided on the basis of both their crown development and crown position relative to the crowns of adjacent trees and the general canopy.

Crown cover

-Ground area covered by a crown, as delimited by the vertical projection of its outermost perimeter.

Crown density

-Thickness, both spatially (depth) and in closeness of growth (compactness) of an individual crown as measured by its shade density. Collectively, crown density should properly be termed canopy density, as distinct from canopy cover.

Crown height

-Vertical distance of a standing tree from ground level to the base of the crown, measured to the lowest live branch whorl or to the lowest live branch or to a point halfway between the two.

Crown length

-Vertical distance of a standing tree from the tip of the leader to the base of the crown, measured to the lowest live branch whorl or to the lowest live branch or to a point halfway between the two.

Crown length ratio

-Of a standing tree, the ratio of crown length to tree height.

Crown thinning

-Removing superfluous live growth in a tree crown to admit light, reduce weight, and lessen wind resistance.

Cruise

-Survey of forest land that includes the location, volume, species, size, and quality of timber stands.

-Estimate obtained in such a survey.

Cutover (Logged over)

-Land that has previously been logged.

Cutter (Logger)

-One who fells, limbs, tops, and/or bucks trees.

Cutting (Logging)

-Process of felling trees.

-Area on which the trees have been, are being, or are to be cut.

Cutting unit

-Area of timber designated for harvest.

Day rate

-Method of paying loggers by the day or hour instead of by the piece.

Deck

-Pile of logs on a landing.

-Area or platform on which wood is placed. Also known as a log landing or log market.

Defect

-Crook, conk, decay, split, sweep, or other injury that decreases the amount of usable wood that can be obtained from a log.

Diameter at Breast Height (D.B.H)

-Diameter of tree stem measured at 4.5 feet (1.3 m) above the ground

Diameter at ground line

-Diameter measure of a standing tree at the estimated cutting height.

Diameter classes

-Classification of trees based on diameter outside bark measured at d.b.h.

Diameter inside (under) bark

-Diameter measurement of a standing tree or log in which the estimated or actual thickness of the bark is discounted.

Diameter limit

-Maximum diameter of trees to be cut, as in a timber sales contract.

Diameter limit cutting

-The cutting of all the trees in a stand above a specified diameter, generally without regard to tree species (can be species specific), quality or individual tree location. The diameter limit may vary by species.

Diameter outside (over) bark

-Measurement of tree diameter in which the bark is included.

Diameter tape

-Tape measure specially graduated so that diameter may be read directly when the tape is placed around a tree stem or log.

Directional (controlled) felling

-Predetermining the way a tree will land when it hits the ground. Wedges may be used to provide a lever that directs the tree into its lay. (NB It is extremely difficult to direct a tree against its natural lean)

Dominant trees

-The most numerous and vigorous species in a mixed forest.

-Larger-than-average trees with well-developed crowns extending above the general canopy level and receiving fall light from above and partial light from the side.

Ecology

-Study of plants and animals in relation to their physical and biological surroundings.

Ecosystem

-A functional unit consisting of all the living organisms (plants, animals, and microbes) in a given area, and all the non-living physical and chemical factors of their environment, linked together through nutrient cycling and energy flow. Ecosystems are commonly described according to the major type of vegetation, for example, forest ecosystem, old-growth ecosystem, or range ecosystem.

Ecosystem management:

-The use of an ecological approach to achieve productive resource management by blending social, physical, economic and biological needs and values to provide healthy ecosystems.

Even-aged

-Stand of trees in which there are only small differences in age among the individual trees.

Even-aged management

-Silvicultural system in which the individual trees originate at about the same time and are removed in one or more harvest cuts, after which a new stand is established.

Experimental plot

-Area of ground laid out to determine the effects of a certain method of treatment.
-Major area-unit of an established experimental study requiring recurrent examination often divided into subplots.

Faller

-One who fells trees. Also known as a feller.

Failing wedge

-Wedge used to throw a tree in the desired direction.

Felling

-Cutting or uprooting standing trees, causing them to fall as a result of the cutting or uprooting.

Field test

-Experiment conducted under field conditions. Ordinarily less subject to control than a formal experiment; it may also be less precise. Also known as a field trial.

Fixed costs

-Operation costs that will remain relatively constant for all levels of output.

Forest (production)

-Area managed for the production of timber and other forest products or maintained as wood vegetation for such indirect benefits as protection of catchment areas or recreation.

(Re-)Forestation

-Establishment of a forest, naturally or artificially, on an area, whether previously forested or not.

Forest ecology

-The relationships between forest organisms and their environment

Forest economics

-Generally, that branch of forestry concerned with the forest as a productive asset subject to economic principles.

Forest floor

-General term for the surface layer of soil supporting forest vegetation; includes all dead vegetation on the mineral soil surface in the forest as well as litter and unincorporated humus.

Forest inventory

-An assessment of forest resources, including digitized maps and a database which describes the location and nature of forest cover (including tree size, age, volume and species composition) as well as a description of other forest values such as soils, vegetation and wildlife features.

Forest management

-The practical application of scientific, economic and social principles to the administration and working of a forest for specified objectives. Particularly, that branch of forestry concerned with the overall administrative, economic, legal and social aspects and with the essentially scientific and technical aspects, especially silviculture, protection and forest regulation.

Forest residuals

-Sum of wasted and unused wood in the forest, including logging residues; rough, rotten, and dead trees; and annual mortality.

Forest structure

-Structure is a pattern in three dimensions, which can be described both horizontally and vertically. And just like a building, the structure of a forest stand often relates or reveals something about the way in which it functions, or its purpose. In the horizontal level, patterns of openings, closed forest, tree size and species are part of the structure. In the third dimension, the number of layers between the ground surface and the uppermost canopy are a key component of structure

Forest technology

-machinery and equipment used in forest management

Forestry

-Generally, a profession embracing the science, business, and art of creating, conserving, and managing forest, and forest lands for the continuing use of their resources, materials, and other forest products.

Forest type

-Classification of forest land in terms of potential cubic

-Foot volume growth per acre at the culmination of mean annual increment (C.M.A.I.) in fully stocked natural stands.

-Classification of forest land based on the species forming a plurality of live-tree stocking. 'Type is determined on the basis of species plurality of all live trees that contribute to stocking.

- A group of forested areas or stands of similar composition (species, age, height, and stocking) which differentiates it from other such groups.

Front end loader

-Wheeled or tractor loader, with a bucket or fork hinged to lifting arms, that loads or digs entirely at the front end.

-Track or rubber-tired machine equipped with forks.

Fuel wood

-Wood salvaged from mill waste, cull logs, and branches; used to fuel fires in a boiler or furnace.

Gap (canopy)

-Opening in the forest canopy

Girdle

-To encircle a tree with cuts to sever the bark and cambium layer, thus killing the tree.

Gravity logging

-Any cable system that depends on the force of gravity for downhill travel of the carriage.

Green strip

-Uncut strip of timber left along streams and roads. Also known as buffer strip, leave strip, streamside management zone.

Ground

-Territory on which a logging operation is being conducted.

Ground clearance

-General term for removing unwanted vegetation, slash stumps, roots, and stones from a site before afforestation or reforestation.

Ground skidding

-Pulling logs parallel to the ground without using an arch or fairlead to raise the forward end.

Growing stock

-Sum (by number or volume) of all the trees in a forest or in a specified part of the forest.

Growth

-Increase in diameter, basal area, height, and volume of individual trees or stands during a given period of time. Also known as increment.

Hang-up

-In felling, to have a tree catch on another so that it becomes lodged.

-In skidding, to get a load stuck in the mud or behind some obstacle.

Hardwood

-Dicotyledonous trees, usually broad-leaved and deciduous.

Harvest

-*In general use* - the removal of some or all of the trees on an area.

- *Technical definition* - a harvest cut is the removal of trees on an area to obtain products and/or income.

Harvesting

-Removing merchantable trees (contrasts with cuttings, which remove immature trees).

Haul

-Conveying wood from a loading point to an unloading point.

-The distance wood is transported.

High grade

-Good (best) quality timber.

Industrial wood

-All round-wood products except fuel-wood.

Intensive forest management

-Utilization of a wide variety of silvicultural practices, such as planting, thinning, fertilization, harvesting, and genetic improvement, to increase the capability of the forest to produce.

Intermediate trees

-Trees with small, crowded crowns below (but extending into) the general canopy level; these trees receive a little light from above and none from the side. May also be referred to as sub-canopy.

Inventory

-A survey of a forest area to determine such data as area, condition, timber, volume and species for specific purposes such as planning, purchase, evaluation, management or harvesting

Land classification

- Classification of forest land in terms of its inherent capacity to grow crops of industrial wood. A site index or the stand age may be used as units of measurements.

- *Site index*-Expression of the growing potential of a specific forest site based on the height of a free-growing dominant or co-dominant tree of a representative species in a forest of the same type at a specified age.

- *Stand age*-Age of trees of the dominant forest type and stand-size class.

Landing

-Cleared area in the forest to which logs are skidded for loading onto trucks for shipment to a saw mill.

Lean

-Degree and direction to which the tree leans from a perpendicular position.

Litter

-Freshly fallen and slightly decomposed plant matter on top of the forest floor

Log

-Length of tree suitable for processing into lumber, veneer, or other wood products.

-To harvest trees on an area.

Logger

-A person employed in the production of logs and/or wood from standing timber.

Logging plan

- Layout, on a topographical map, of roads, landings, and setting boundaries of a logging area.

Logging residues

-Unused portions of growing stock from trees cut during by logging.

Logging truck

-Vehicle used to transport logs.

Machine rate

-Cost per unit of time for owning and operating a logging machine or some other piece of logging equipment. In accordance with engineering practices, the rate is composed of fixed costs such as depreciation, interest, taxes, and license fee, and variable costs including fuel, lubricants, and repairs and replacement of components.

Man-hour

-Unit of work performed by one man in 1 hour.

Marking

-Selecting and indicating, by a blaze or paint sport, the trees to be cut or left in a timber cutting operation.

Mature timber

-Stand of trees that has attained an age or size that satisfies the primary economic goal for which it was managed.

Mean annual increment

-Average growth per year.

Mensuration

-In forestry, the measurement of both standing and harvested timber.

Merchantable

-Logs exceeding a minimum size and a minimum usable volume that are suitable for sale.

Model (mathematical)

-Theoretical abstraction, usually capable of mathematical manipulation, used to evaluate a problem or a subject of interest.

Multiple entry

-Entering a stand for commercial harvesting more than once in any one continuous rotation.

Multiple-use management

-Management of land resources with the objective of achieving optimum yields of products and services from a given area without impairing the productive capacity of the site.

Natural regeneration

-Renewal of the forest achieved either by natural seeding or from the vegetative reproduction of plants on the site.

Net annual growth

-Increase in volume of trees during a specified year. Components of net annual growth include the increment of net volume of trees at the beginning of the specified year that survive to the year's end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year, and minus the net volume of trees that become rough or rotten trees during the year.

Net scale

-Actual amount of merchantable wood contained in a log as opposed to the gross scale, which includes defect.

Non-commercial species

-Tree species in which small size, poor form, or inferior quality is typical. These species do not normally develop into trees suitable for conventional forest products.

- Tree species with no commercial value.

Notch

-To make an undercut in a tree, preparatory to felling it in a given direction. Also known as a box or an undercut.

Old growth

-Growth in a mature forest.

Operational cruise

-Timber inventory that includes the estimation of timber volumes or other stand information on specific geographic areas for specific purposes, as contrasted with more broadly based estimates for forest wide planning.

Operations research

-Scientific approach to decision making that involves the operations of organizational systems.

Optimum road spacing

-Distance between parallel roads that gives the lowest combined cost of skidding and road construction costs per unit of log volume.

Overstorey

-Tall mature trees that rise above the shorter immature understorey trees.

Overstorey removal

-Any silvicultural treatment with the desired end result being the removal of the overstorey component from the growing stock of a multi-storied stand. Examples are outright harvest, poison girdling, and simply felling the overstorey.

Parent tree

-Any tree whose seeds are used to produce progeny for regeneration

Partial cut

-Logging area in which only part of the trees are felled and skidded, as opposed to clear-cut.

Periodic annual increment

-Mean annual growth or increase in volume during a specific period of time.

Piece rate

-Payment for labour where income is related to output.

Pioneer (shade intolerant species)

-Fast-growing, early successional plant species. Usually found in disturbed areas

Plantation

-Forest stand regenerated artificially either by sowing or planting. May also be referred to as (manmade forest).

Planting

-Artificial regeneration method in which a new stand of trees is established by restocking the area with tree seedlings.

Plunge cut

-Starting a cut in the centre of a log using the tip of the chain saw blade. Also known as boring.

Pole

-Young tree at least 4 inches and less than 8 to 12 inches in d.b.h.

-Any considerable length of round timber below saw log size, ready for use after removal of the bark without further conversion.

Potential yield

-Estimated maximum sustained yield cutting level (stated for a period of time such as a year or decade) attainable with intensive forestry; considers productivity of the land, conventional logging technology, standard cultural treatments, and interrelationships with other resource uses and the environment.

Prescribed burning

-Deliberate use of fire under conditions where the area to be burned is predetermined and the intensity of the fire is controlled.

Preventive maintenance

-Maintenance measures taken in advance to avoid breakdowns.

Primary logging road

-Road designed and maintained for a high level of use by heavy vehicles. Typically an all-weather gravel road that is part of a permanent road system.

Reduced Impact Logging

- A series of distinct components or steps designed to minimize the disturbances associated with (conventional) selective timber harvest. It adapts the best possible harvest techniques to local site and market conditions.

Reforestation

-Restocking an area with forest trees.

Regeneration

-The renewal of a tree crop through either natural means (seeded on-site from adjacent stands or deposited by wind, birds, or animals) or artificial means (by planting seedlings or direct seeding)

Residual stand

-Trees remaining in an area after the cutting operation has been completed.

Residue

-Wood or bark that is left after a manufacturing process.

Rotation

-Period of years between establishment of a stand of timber and the time when it is considered ready for final harvest and regeneration.

Round wood

-A length of cut tree generally having a round cross-section.

Round wood products

-Logs, or other round sections cut from trees for industrial or consumer use.

Sapling

-Young tree stem ranging from 1 – 6 inches d.b.h (may also be referred to as a pole)

Secondary logging road

-Road designed for relatively little use. Typically a dirt road, with no gravel, used only during dry weather.

Secondary growth

-Trees that regenerate naturally after the first growth of timber has been cut or destroyed.

Seedling

-Young tree grown from seed, from the time of germination until it reaches sapling size.

Seedling and sapling stands

-Where 10 percent of the stand consists of growing stock trees, and saplings and/or seedlings constitute more than half this stocking.

Seed tree

-Tree that produces seeds; usually a superior tree left standing at the time of cutting to produce seeds for regeneration. May also be referred to as a parent tree.

Selection cutting (selective harvesting)

-Cutting only a portion of the trees in a stand, usually those marked or designated by a forester.

Shade Intolerant (Pioneer) Species

-Tree relatively incapable of developing and growing normally in the shade of, and in competition with, other trees.

Shade tolerant (Climax) Species

-Trees with the ability to grow in the shade

Shelter wood logging

-Method of harvesting timber so that selected trees remain scattered throughout the tract to provide seeds for regeneration and shelter for seedlings.

Shelter wood system

-Even-aged silvicultural system in which a new stand is established under the protection of a partial canopy of trees. The mature stand is generally removed in a series of two or more cutting cycles, the last of which is when the new even-aged stand is well developed.

Silvicultural system

-Process of tending, harvesting, and replacing forest trees, which results in the production of forests with distinct compositions. Systems are classified according to the method of harvest cutting used for stand reproduction.

Silviculture

-Generally, the science and art of cultivating (such as with growing and tending) forest crops, based on the knowledge of silvics. More explicitly, the theory and practice of controlling the establishment, composition, constitution, and growth of forests.

Site class

-Classification based on ecological factors and the potential production capacity of an area; a measure of the relative production capacity of a site.

Skid

-Load being pulled by the skidder.

Skidder

-rubber tired machine made to skid logs or trees. Logs are either pulled by cables, chains, or a grapple.

Skidding

-Transporting trees or parts of trees by trailing or dragging them from stump to a collection point.

Skid trail

-Temporary road for skidder travel to landing

Slash

-Woody material or debris left on the ground after an area is logged.

Snag

-Standing dead tree

Soil compaction

- Increased soil density resulting from the packing effect of machines moving over the soil. Compaction disturbs the soil structure and can cause decreased tree growth, increased water runoff, and soil erosion.

Species

-Group of similar individuals having a number of correlated characteristics and sharing a common gene pool. The species is the basic unit of taxonomy on which the binomial system has been established and is both the singular and plural form of the word.

Sprouting

-New tree (or branches) arising from an old tree or remnant of an old tree. Can occur from roots and stumps.

Spur road

-Road that supports a low level of traffic, such as a level that would serve one or two settings. Little or no engineering design work is needed to build it.

Stand

-Section of a forest with sufficient uniformity to be distinguishable and to be managed as a single unit

-*In silviculture and management* - a tree community that possesses sufficient uniformity in composition, constitution, age, spatial arrangement, or condition to be distinguishable from adjacent communities. This tree community forms a silvicultural or management entity; for example, a sub-compartment. Both natural and artificial crops are included, and there is no connotation of a particular age.

-*In mensuration* - the amount of timber and/or fuel wood standing on an area, generally expressed as volume per unit area.

Stand density

-Quantitative measure of tree stocking frequently expressed in terms of number of trees, basal area, or volume per unit area.

Stand improvement

-Measures such as thinning, release cutting, girdling, weeding, or poisoning of unwanted trees to improve growing conditions.

Stand table

-Table showing the number of trees by species and diameter classes, generally per unit area of a stand

Stem

-Main body of a tree from which branches grow.

-Used loosely to refer to trees. For example: stems per unit area.

Stocking

-Degree of utilization of land by trees. Measured in terms of basal area and/or the number of trees in a stand compared to the basal area and/or number of trees required to fully utilize the growth potential of the land.

Succession:

- Natural change in vegetation (tree species) over time following a disturbance.

Sustained yield

-Timber yield that a forest can produce continuously at a given intensity of management. It implies continuous production planned to achieve a balance between growth (increment) and harvest at the earliest practical time.

Thinning

-Cuttings made in immature stands in order to stimulate the growth of the trees that remain and to increase the total yield of useful material from the stand.

Timber

-General term applied to forests and their products.

Timber appraisal

-Economic appraisal of the monetary value of a timber stand.

Timber harvesting impacts

- The impact (environmental, economic and social) of the removal of some or all of the trees in an area.

Timber stand improvement

-Intermediate thinning of a forest stand, prior to its reaching mature rotation age, generally for the purpose of improving growing conditions or controlling stand composition.

Timber volume

- Volume of sound wood in the bole of sawn timber and pole timber from a stump to the point where the central stem breaks into limbs.

Tree

-Woody plant that usually grows to at least 20 feet (6 m) in height at maturity, typically having a single trunk with no branches within 3 feet (0.9 m) of the ground.

Undercut

-Wedge-shaped notch cut in the base of a tree to govern the direction of its fall. Also known as a box or a notch.

Understorey

-Young trees that are growing beneath the tall mature trees in a forest.

Uneven-aged

-Stands composed of intermingling trees that differ markedly in age within a minimum range of 10 to 20 years.

Uneven-aged management

-Silvicultural system in which individual trees originate at different times and result in a forest with trees of all ages and sizes. Harvest cuts are on an individual-tree selection basis.

Winch

-Steel spool connected to a power source. Used for reeling or unreeling cable. Also known as drum.

Windfall

-Tree or trees that have been uprooted or broken off by the wind.

Yield

-Estimate in forest mensuration of the amount of wood that may be harvested from a particular type of forest stand by species, site, stocking, and management regime at various ages.

Yarding

-Initial hauling of a log from the stump to a collection point. May be referred to as skidding.

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Andaman and Nicobar Islands				Volume of timber remaining in the forest in the form of buttressed stumps was 8.2 m^3/ha for hardwoods and 5.89 m^3/ha for softwoods Removal of the buttress before felling would minimize timber damage, increase timber yield and keep the forest floor in a more hygienic condition				Balachandra, L. 1988
Africa	Tropical moist forests · well planned and carefully controlled harvesting systems are superior economically, environmentally and silviculturally Such harvesting systems should be fully integrated with the management system, but has been an elusive goal in the tropics		Total bole volume in Francophone African countries average 111 m^3/ha, of which 61 m^3/ha (11.5 trees/ha) is of commercial size (>70 cm dbh), and of which 15 m^3/ha (2.3 trees/ha) is commercial volume of preferred species In polycyclic silviculture, systems must use RIL, in which case on a 30 year cycle and 1 cm/a dbh growth logging will be sustainable In Côte d'Ivoire they are confident that the majority of stems in the 20-40 and 40-60 cm dbh classes will move up to the next class with a 40-year logging cycle		Soil disturbance on 20-25% of logged area Every felled mature tree destroys 200-400 m^2 of forest			FAO 1989a
Africa	Successive felling at a very short interval associated with poor forest inventory is not compatible with sustainable management.		Logging intensity 1-2 trees/ha or 15-20 m^3/ha		Generally less than 10% of the original tree population damaged during logging			Sist, P. 2000

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Africa (central)	• The main objective of the "ECOFAC" project was to determine the relation between harvesting intensity and damage to the residual stand.		• Minimum harvesting diameter 80cm dbh (few trees <90cm dbh were cut) • The harvesting from 0.4 - 4 trees/ha		• Most of the damage was caused during skidding operations • 0.8% of the surface was affected by roads and landings.			Durrieu de Madron, L., Fontez, B., Dipapoundji, B. 2000
Africa, Anglophone west			Felling cycles • Cameroon 30-60 years • Nigeria 50 years • Ghana 40 years • Optimum felling cycle is one that ensures complete forest recovery and sufficient stem recruitment into the exploitable diameter class • Felling limits vary between 50-110 cm dbh depending on country and species	• In S.E. Asia 33-67% of the residual trees are damaged by logging	• In S.E. Asia 33% of the total area is damaged during logging			Dykstra *et al.* 1996
Amazonia	• In this study, the effects of logging intensity, time after logging, and skidder tracks, on the composition and diversity of the ground-level herb community of a terra-firme forest in central Amazonia were examined. • We conclude that forest managed with logging intensities similar to those used in this experiment could be compatible with conservation of understory herbs. • Skidder tracks should be minimised, as they have the greatest long-term impact and allow species from other habitats to invade the forest.		• Logging was carried out at varying intensities in eight 4-ha experimental plots in 1987, three plots in 1993, and five plots were controls.		• Results indicate that the herb ground community is not severely affected by selective logging at the intensities used in this experiment. • The alterations in composition are mainly local, and restricted to the most disturbed patches.			Costa, F. & Magnusson W. 2001
Amazonia (Brazil & Bolivia)	• Forest owners and operators in Brazil and Bolivia were interviewed in order to assess the level of implementation of RIL in the two countries. • In Bolivia the companies making the most progress towards RIL implementation are large, well organized and vertically integrated; whilst in Brazil those						• Two of the main obstacles facing RIL implementation in both countries is the perception that RIL is prohibitively expensive and the lack of trained people at all levels.	Blate, G.M., Putz, F.E. & Zweede, J.C. 2001

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	companies making most progress towards RIL adoption are those with enough capital to invest in appropriate technology and training of personnel. • Companies in Brazil and Bolivia have adopted the RIL elements that increase efficiency, reduce costs, enable them to comply with the law, and help them improve marketing. • In Bolivia, improving market access through certification is probably the most important reason for RIL adoption whilst in Brazil, increased operational efficiency and consequent cost savings.							
Asia-Pacific	• A necessary condition for implementing RIL is that personnel have the qualifications to perform their tasks and responsibilities effectively and efficiently. • Personnel need to know and understand the nature and scope of the work to be done, why it has to be done and how best to do it. In combination, these skills enable them to carry out complex tasks efficiently. Thus, greater efficiency and higher productivity in timber extraction under RIL is achieved through training. • RIL training often concentrates on felling/bucking and skidding operations simply because their negative impacts on the residual stands and the forest ecosystem as a whole are highly visible, and readily measurable in physical and monetary terms. • This approach often fails to recognize that other key stakeholders, such as policy-makers, planners and supervisors also need to undergo training because their decisions have significant and long-term impacts on the productivity and sustainability of the forest resources.							Vergara, N.T. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Asia-Pacific	• A basic attraction of RIL is that forests continue to provide economic potential through timber production while improving the environmental value • 50% of the green-house-gas-benefits are realised over the first few years.						• Increasing interest in using carbon offset financing to carry out more environmentally sound forest management • RIL provides little monetary incentives for forest concessionaires to invest in these techniques.	FAO 1998
Asia (South East)			• Logging intensity 8 trees/ha or 80-100 m^3/ha		• >50% of the original tree population are damaged during logging			Sist, P. 2000
Asia, Southeast	• Elephants are a low cost, low impact means of hauling logs in the forest. • However no studies comparing the damage level caused by elephant and conventional machine-based logging appear to have been carried out, but some general observations can be made.				• When elephants are used, skid trails in the logging area are not required, greatly reducing the amount of mineral soil exposed. • Elephants can also be used to float logs down shallow streams, reducing the need for access roads. • They can however cause soil compaction over defined trails through the forest, although the area affected is much less than under conventional tractor logging.			Grace, K.T. & Adnan, A. 1996
Asia, Southeast	• A model was constructed to simulate changes in biomass and carbon pools following logging of primary dipterocarp forests in southeast Asia. • A physiologically driven tree-based model of natural forest gap dynamics (FORMIX) to simulate forest recovery following logging.				• The relationship between fatal stand damage and ecosystem carbon storage was not linear, with biomass recovery following logging severely			Pinard, M.A. & Cropper, W.P. 2000

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	• Following selective logging, simulated ecosystem carbon storage declined from prelogging levels (213 Mg C ha-1) to a low of 97 Mg C ha-1, 7 years after logging. • Carbon storage in biomass approached prelogging levels about 120 years after logging.				limited by 50-60% stand damage. • Results suggest that when 20-50% of the stand is killed during logging, replacing persistent forest species with pioneer tree species can reduce the site's potential for carbon storage by 15-26% over 40-60 years.			
Asia, Southeast	• The integration of silvicultural principles and guidelines is essential for improving RIL techniques towards sustainable harvesting practices. • Four of these silvicultural principles are: (a) minimum diameter cutting limit based on stand structure (b) Minimum spacing distance of 35 m between harvested trees (c) Single-tree felling gaps and (d) maximum diameter cutting limit. • These principles aim at keeping extraction rates below set thresholds; limit the impact of harvesting on the stand and maintain timber species populations.							Sist, P. 2001
Australasia	• Tasmania has pioneered improvements in forest operations within the Australian forest industry, with the introduction of the Forest Practices Act in 1985, of which the Forest Practices Code (FPC) is an integral part. • The code outlines minimal environmental standards that must be achieved for all forest operations, including guidelines to reduce the impact of logging. • The Vanuatu Code of Logging Practice (VCOLP) was introduced in 1998, using the existing Forestry Act as the basis for legislation (Vanuatu Department of Forests, 1997a).							Andrewartha, R. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	• Full compliance with all operating standards was to be achieved by 31 December 2000. • Complementary to the code, reduced impact logging (RIL) guidelines were formulated designed to assist field supervisory staff and industry operators in executing forest-harvesting plans (as required by the VCOLP).							
Australia, Queensland	• Queensland selective logging system studied most important to further reduce damage is to enhance the skills, sensibilities and cooperation of field personnel		• Average logging intensity 6.6 stems/ha, 4.9 m^2/ha, 37 m^3/ha	• 146.7 stems/ha killed during logging amounting to 12 m^2/ha of basal area • Damage less than in other studies done in SE Asia · more fibre from crowns could have been utilized	• Machine trails occupy 5% of area • Canopy loss was 19.5% of area • 18 months after logging casual observations indicated there was little regeneration on the major logging tracks • Logging did not result in the loss of any tree species from the sample sites nor was there any change in the total plant species list after logging			Crome *et al.* 1992
Australia, Queensland	• Tropical forests • 14 species comprised 95% of volume removed, and 4 species comprised 50% of volume		• Logging intensity 8-10 trees/ha or 50-55 m^3/ha in 1987-1990 • In 1979-1980 logged areas, the logging intensity was 34 m^3/ha					Laurance, W. & Laurance, S. 1996
Australia, Queensland	• Harvesting model which enables estimation of selection logging yields and quantification of impact on the residual stand • Residual stem prediction equations derived from a series of 9 logging damage studies from 1977 to 1980 • Amount of basal area logged was one of the major variables		• Minimum cutting limit for defective trees 40 cm, but otherwise 60-100 cm dbh depending on species • In the logging damage studies 13.8% of the original stand stems were marked for removal and extracted, while 1.2% were marked, felled and left as		• From the logging damage studies 10% of original stand stems were destroyed, while 11.5% were damaged but would probably survive			Vanclay, J. 1989

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
			unmerchantable • 38 years after logging, tree marking in a previously logged stand reached the same selection intensity as in a virgin stand					
Belize	• The stands on this site were logged 10 or more years ago and had an intact canopy • The harvest rate for mahogany far exceeded the regeneration and recruitment capacity of the forest.			• Because similar numbers of commercial and non-commercial species were damaged, loggers did not appear to make an effort to avoid damaging species of commercial value.	• Skid roads covered 3.8% and affected another 6.3% and thus accounted for 78% of the disturbed area • Logging gaps covered 2.28% and accounted for the remaining 22% of the disturbed area • The soil was significantly compacted on 3.8% of the study area • The soil was twice as compacted on skid roads than in adjacent forest • Soil compaction was over 200% greater on roads where more than one tree had been skidded			Whitman, A.A., Brokaw, N.V.L & Hagan, J.M. 1997
Bhutan	• Natural forests of the Himalayan range in Bhutan • The study was focussing on "environmentally friendly forest engineering"				• Focussing on environmental impacts of road construction, the superiority of excavator technique in difficult and/or steep terrain over bulldozer techniques becomes obvious although the short-term benefits might favour the use of bulldozers		• A productivity of 3.88 m^3/h was found for cable logging in CL and 5.01 m^3/h in RIL • The costs of timber extracted by long-distance cable crane amounts to US$ 25.53/m^3 for CL and US$ 20.13/m^3 for RIL • The total costs for roads were US$ 9.28/m for excavator	FAO 1999

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
							construction and US$ 6.07/m for bulldozer construction	
Bhutan	• Prior to the early 1970s, logging was carried out manually and impacts on the soil, the residual stand and hydrology were high. • Bhutan has endeavoured to achieve high standards of environmental protection by adopting more appropriate management, road construction and harvesting techniques. • Bhutan's development policies are aimed also at maintaining cultural values for its population, which is heavily dependent on the forests. • The pursuit of these policies has required a limited amount of commercial forest exploitation in order to create revenues for national development. • Generally, Bhutan has been successful in achieving its environmental and social development goals, partly through the adoption of appropriate technology and techniques and partly due to a clear vision that has allowed decision-makers to follow a consistent course of action.							Thinley, U. 2002
Bolivia	• Bosque Chimanes • The value of previously logged forests for future timber production, and the contributions of these forests to the conservation of biodiversity will depend to a large degree on how much damage is done to the forest during the initial log extraction		• First pass is 95% mahogany in 602 ha study area 74 commercial mahogany trees extracted (= 0.12 trees/ha)		• Area under roads 6.31 ha or 1.05% (main road 4993 m long and 6.62 m wide, skid trails totalled 8523 m and 3.53 m wide) • Felling gaps ranged from 100 to 1000 m^2 (average 380 m^2), resulting in 2.81 ha of gaps or 0.47% of area • Road secondary damage was 17.29 ha or 2.87% of area • Total area directly under roads,			Gullison, R. & Hardner, J. 1993

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					secondary damage and gaps was 26.41 ha or 4.39% of area • Road damage could have been reduced by 25% through better planning (straight main road with skid trails running off of it) • On the other hand more disturbance is required to get sufficient regeneration of mahogany			
Bolivia	• Significant quantities of mahogany (total volume 159-180 m^3/ha and 100 m^3/ha respectively) were found in the study area.		• Minimum cutting diameter of 80cm dbh	• 10% of commercial sized trees should be left as seed trees • Processing efficiency at the mill is estimated as 60% • Quantities of residual branch wood are substantial, ranging from 0.85 m^3 to more than 16.3 m^3 per tree • Utilisation of mahogany ranged from 49.2 to 90.5%, and decreased significantly with increasing diameter • Stem cut-offs, buttresses and the stump usually account for 20.2% of the total tree volume				Gullison, R. & Hardner, J.J. 1997
Bolivia			• Harvest intensity ranged from 1-6 trees /ha	• Damage level for the residual basal area was very low (mortality mainly in smaller size classes)	• Both harvest mortality and total mortality were quadratic increasing functions of harvest intensity when expressed in terms of basal area.			Panfil, S.N. & Gullison, R.E. 1998

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Bolivia	• The impact of skidder disturbance on recruitment of commercial tree regeneration within logging gaps was studied using paired scarified and unscarified plots as well as whole-gap surveys of scarified and unscarified areas in a Bolivian tropical humid forest.			• More than a year following gap creation, variability in the density of regeneration among logging gaps was high, but commercial tree regeneration density tended to be greater in scarified areas than in unscarified areas within gaps for most species. • Although initially devoid of vegetation and litter cover, scarified areas had vegetation and litter cover levels similar to unscarified areas after 7 months. • Vegetation cover on scarified areas tended to be dominated by early successional tree species while unscarified areas were dominated by forbs and grasses.				Fredericksen, T.S. & Pariona, W. 2002
Bolivia	• Nearly 1 million hectares of Bolivian forest are now certified by the Forest Stewardship Council. • To ensure sustainable forest management, however, Bolivian foresters need to go beyond the basics of planned logging and apply silvicultural treatments to secure regeneration, improve tree growth and maintain stand quality. • This change is a tall order in a developing country battered by a deep economic recession, where timber-mining interests are still powerful and silviculturists are in short supply.							Fredericksen, T.S., Putz, F., Pattie, P., Pariona, W. & Pena-Claros, M. 2003
Bolivia	• The area disturbed and damage to the residual stand caused by planned diameter-limit logging was assessed in a tropical humid forest of Bolivia and compared with disturbance and damage reported in other studies in the neotropics	• The harvest incorporated many reduced impact logging practices including pre-harvest tree	• A total density of 4.35 trees/ha and 12.1 m^3/ha of wood were harvested.		• It was estimated that logging disturbed 45.8% of the stand including 25% ground area disturbance in the			Jackson, S.M., Frederickson, T.S. & Malcolm, J.R. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	with similar harvesting intensities.	inventories, planned placement of roads and skid trails, vine cutting, and directional felling.			form of skid trails, logging roads, and log landings and an additional 25% in canopy openings due to tree felling. • On average, 44 trees were damaged for every tree extracted including 22 trees killed or severely damaged, 6 of them commercial species. • The most common types of damage included uprooted stems, stem wounds to the cambial layer, and bark scrapes. • Damage to trees sustained along skid trails was found to be significantly less than the damage incurred along logging roads. • Residual damage in felling gaps was positively related to the diameter-at-breast height of the harvested trees. • Comparisons with other planned operations revealed a higher percent ground area disturbed and a greater felling gap area per tree extracted. • Higher ground area disturbance was mostly due to the greater area in skid trails, many			

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					of which appeared to be unnecessary. • Larger felling gap sizes appeared to be at least partially attributed to the larger size of trees harvested relative to those in other forests.			
Bolivia	• One-year-old logging gaps were sampled in dry and humid selectively-logged Bolivian tropical forests to determine the density of commercial tree regeneration. • Liberation treatments designed to enhance the growth and survival of sapling regeneration was evaluated over a period of 2 years.			• Of the nine species harvested in each forest type, only two species in each type had relatively abundant regeneration in logging gaps. • Only two species in each type had relatively abundant regeneration in logging gaps			• Treatment costs were relatively low US$1-2.3 per gap), but time until return on investment is long (20-30 year cutting cycles).	Pariona, W., Fredericksen, T.S., Licona, J.C. (in press)
Brazil	• Article summarises key findings of the IMAZON low impact logging study		• Brazilian producers can yield an additional 7.3 m^3/ha by introducing RIL • Harvesting cycle of 70 years with CL may be reduced to 25-30 years through RIL	• CL: 7 m^3/ha of wood lost during skidding operations by not finding all felled trees • 0.3m^3/ha were lost due to poor felling and bucking practices	• RIL: 5% of the block area disturbed by skid trails, roads and log decks • RIL: 30% fewer trees damaged and 25% less of the canopy disturbed when compared to CL		• RIL machine time reduced by 20%	Blate, G. 1997
Brazil	• Based on the IMAZON reduced impact logging study				• RIL: damage to residual stand reduced by 30% compared with CL • RIL: soil disturbance is significantly reduced	• Up to 19% of the harvest volume (7m^3/ha) were left behind because skidder operators could not locate the logs		Bowyer, J.L. 1997
Brazil	• Average growing stock (dbh >10 cm) was 247.9 m^3/ha or 133.9 m^3/ha for trees with dbh >50 cm • When the subject of sustaining wood production over a number of cutting cycles is considered, it becomes obvious that planned exploitation is the key to ensuring		• Logging intensity 20 m^3/ha		• With RIL maximum canopy opening was 15% • 22.5 m/ha of road built (5 m wide), 60 m/ha of skid trails • With RIL the			d'Oliveira, M. & Braz, E. 1995

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	that the growing stock is maintained at a desirable level				number of damaged trees (dbh >10 cm) per tree logged was 5.3 (or 0.27 m^3 damaged per m^3 extracted)			
Brazil	• This study was carried out in the Amazon region of Brazil, testing the applicability of the *FAO Model Code of Forest Harvesting Practice.*		• Harvesting cycle of 25 years · The average harvesting intensity is 35m^3/ha with a maximum of 40m^3/ha (about half of the average harvestable volume per hectare found for the project area) • RIL: the timber removal amounted to 33% of the volume found by the commercial inventory prior to harvesting (equals 26% of the trees of commercial interest) • CL: timber removal amounted to 73% of the volume and 69% of the trees of commercial interest.	• The total timber losses amounted to 8.5% in the CL area and 3.9% in the RIL area. • In both units losses due to skidding or caused by forgotten, unextracted logs did not occur since all trees had been numbered.	• Severe harvesting damage to potential crop trees was found to be more than twice as high with the traditional logging system (51.5%) as compared to the environmentally sound forest harvesting system (22.2%) • RIL: skid trials occupied 4.2% of he total area, whereas in the CL system the affected area amounts to 18.7% • RIL caused canopy gaps totalling 10.8% of the area while CL resulted in canopy gaps on 24.7% of the area		• Referring to the costs of CL per cubic metre of saw log at landing site as 100%, the costs of RIL come to 109% and would amount to 101.5% if RIL had been carried out according to the planned changes	FAO 1997c
Brazil	• Currently the study site is managed for the production of commercial timber, palm hearts and honey.		• Harvesting reduced the stand density from 851 to 645 trees/ha (basal area reduced from 48.5 to 29.2 m^2/ha), • A cutting cycle of 12 years at 25% harvesting • The annual harvesting rate would equal 2.56 m^3/ha intensity appears to be sustainable	• Harvesting intensities of up to 25% of the basal area ensure sufficient regeneration of primary forest tree species.			• A comparison of management scenarios for a forest area of 2208 ha indicated that sustainable management practices result in a present value of US$ 2.2 million compared to US$ 5.6 million with timber exploitation.	Hering, K.G. 1993
Brazil	• Study of RIL with vine cutting 18 months prior to logging • Directional felling made 85% of the			• Improved skidding operations resulted in less forest damage,	• RIL looked much better, skid trails had good			ISTF 1995

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	felled trees easier to skid · vine cutting, directional felling and removal of buttresses clearly helped reduce damage and increased skidding efficiency • The potential impact of an industry conversion to RIL is enormous • Adoption of RIL throughout the tropics would result in more efficient use of production forests which in turn would reduce pressure on primary forests • IMAZON results suggest costs may be reduced by one-third with RIL			less timber extraction time and lower extraction cost, than in the conventionally logger area	regeneration and canopy cover, the canopy openings looked very similar to natural tree fall gaps			
Brazil							• RIL: the main costs arise in the planning stage • RIL could result in a net financial benefit of US$ 3.70 per m^3 (Barreto *et al.*1998)	Sist, P. 2000
Brazil	• The study was carried out in floodplain forest • RIL: logs are floated out of the forest (few environmental impacts)		• RIL: highly selective harvest, with only 1-2 trees/ha removed • CL: harvesting intensity >10 trees/ha (50 species harvested) • With RIL sustainable cutting cycles might be reduced from 70-100 years to 30-40 years • Cutting cycles of 50 years and harvesting intensities of 5 trees/ha were proposed	• CL: approximately 30% of each harvested log is converted into sawn wood. • Processing efficiency could be increased to nearly 50% through simple improvements in machinery maintenance and by training the workers	• Logging often changes to high impact practices as frontiers age and infrastructure and access to markets improve • RIL: 25% reduction in the ground area affected by machine movements • Vine cutting two years before logging, resulted in a 30% reduction in damages to trees >10cm dbh	• CL: 7 m^3/ha are felled but never found by the skidder operator • CL: Waste associated with felling and bucking could be reduced to 30% by training loggers	• RIL has an added cost of US$ 50 /ha for forest inventory, vine cutting and careful planning • The monetary losses from CL through unnecessary wood waste may be greater than the additional costs of implementing RIL • Machine operation time could be reduced by 20% through implementing RIL	Uhl, C., Barreto, P., Verissimo, A., Vidal, E., Amaral, P., Barros, A.C., Souza, C. Johns, J. & Gerwing, J. 1997
Brazil	• Objectives were to determine vine species composition, stem densities, and the abilities of different vine species to resprout following cutting				• Vine cutting prior to logging can reduce logging damage		• Vine cutting costs approximately US$ 16 per hectare. • This is equivalent to 8% of the profits of a typical logging-only operation • These costs could be reduced by	Vidal, E., Johns, J. Gerwing, J.J., Barreto, P. & Uhl, C. 1997

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
							focusing efforts on aggressive species likely to cause problems	
Brazil (Amazon)	• The results of the CELOS Silvicultural System Study were applied to 80,000 ha • The basal are of the initial stand was 30 m^2/ha.		• Felling cycle of 20-30 years · The maximum harvesting intensity was 30m^3/ha • The target diameter is 60cm dbh • Where forest management proceeds towards classical selection felling in succeeding cycles, the frequency of harvesting may be increased to 5-10 years, with a low volume taken per ha.	• Applying RIL for production of marketable timber without any further steering of forest development will probably result in a steady decrease in standing volumes of timber of marketable species.	• It is estimated that about 5% of the area is influenced, mainly by compaction , by machines, mostly due to permanent infrastructure (skidding trails, log landings, truck roads)		• The cost per m^3 of standing round wood produced is in the order of half a man-day.	de Graaf, N.R. 2000
Brazil (Amazon)	• This study was designed to evaluate long-term impacts on soil properties in areas harvested with a selection system.		• An average of 16 trees/ha was harvested (equal to a volume extraction of 75 m^3/ha) • Cutting limits of 55cm and 45cm dbh respectively were applied		• 16 years after harvesting, 99% of the area were classified as minimally disturbed, 1% as skid trails • Bulk density data indicated that soils remained compacted in all disturbance classes after 16 years			McNabb, K.L., Miller, M.S., Lockaby, B.G., Stokes, B.J., Clawson, R.G., Stanturf, J.A. & Silva, J.N.M. 1997
Brazil (Eastern Amazon)	• Study compared the net present value for 20and 30 year cutting cycles with and without forest management		• The logging intensity ranged from 35 to 40 m^3/ha • With RIL, 68% more timber volume could be extracted over a 30-year period		• RIL techniques reduce damage to the forest, leaving a well-stocked stand.	• CL: 26% of the volume of felled timber was wasted • RIL: 1% of felled timber was wasted	• The cost to plan logging operations was estimated as US$ 72/ha or US$ 1.80 - 2.50/ m^3 • RIL operation resulted in financial benefits of US$ 3.7/m^3, (2x cost of planning) • Using discount rates from 6 to 20%, the net present value of timber extraction were 38 to 45% with RIL	Barreto, P., Amaral, P., Vidal, E. & Uhl, C. 1998

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Brazil (Eastern Amazon)			• 20, 40 and 60% of all trees over 40cm dbh were harvested		• Restricting vehicles to designated trails significantly reduces the total area affected • Signs of soil compaction were found 12 years after skidding		• The position of the log after felling is directly correlated with the operational productivity	FAO. 1997b
Brazil (Eastern Amazon)	• By reducing the size of logging gaps RIL techniques can reduce the risk of fire		• Cutting cycle of 30-50 years were applied • Extraction intensity 30-40m^3/ha		• RIL reduced the mean size of canopy gaps by 53% relative to CL.		• RIL: US$ 50/ha are required to carefully plan and execute logging operations	Holdsworth, A.R. & Uhl, C. 1997
Brazil, Amazon	• Várzea • Terra firme		• Logging intensity averages 4-5 trees/ha • Logging intensity of 4-5 trees/ha	• Loss of only about 5% of standing trees • Total loss of 60% of standing trees due to heavy equipment, landings & roads				Ayres, J. & Johns, A. 1987
Brazil, Amazon	• Para State • Small sawmill LRF 35.1% • Medium sawmill LRF 34.3% • Veneer and plywood mill recovery • 37.2% with logs floated from as far as 2500 km		• In the Varzea forest the average logging intensity is 56 m^3/ha (N. Maciel, pers.comm. 1994) • In terra firme forest the average logging intensity is 38 m^3/ha (Verissimo *et al*. 1992)					Barros, A. & Uhl, C. 1995
Brazil, Amazon	• Para State • Wood waste and increased canopy openings increase fire risk • Wood processing industry is old and inefficient • Conventional logging gives 30 m^3/ha @ 35% lumber recovery or 10.5 m^3/ha of lumber, while planned logging and more efficient processing gives 38.3 m^3/ha @ 50% lumber recovery or 19.2 m^3/ha of lumber (increase in product yield of 83% per ha)		• Felling intensity typically 30 m^3/ha (volume extracted)	• Majority of trees found were buried under the crowns of other trees or isolated from other timber trees (i.e., lack of map for skidder showing locations of felled trees)	• In conventional logging 28.7 trees (dbh >10 cm) were damaged per tree felled, compared to 20.5 trees with planned operation • In conventional skidding 11.5 trees were damaged for each log skidded, compared to 4.4 trees damaged per log skidded in planned operations	• In three previously logged sites 6.6 m^3/ha of usable timber was felled but never skidded (represents 1 tree/ha) • Other waste was high stumps, improper felling so log splits, bucking too far from top (these losses totalled 0.41 m^3/tree or 2.3 m^3/ha or 7% of the harvestable volume • With a trained		Gerwing *et al.* 1996

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
						feller and directional felling similar losses were 0.11 m^3/tree or 1.7 m^3/ha less wastage		
Brazil, Amazon	• Terra firme forest		• Logging intensity 35 m^3/ha					Ivo *et al*. 1996
Brazil, Amazon	• Terra firme rain forest • Amazonas State • Initial stand basal area 35 m^2/ha		• Logging during 1975-1985 with a logging intensity of 3-5 trees/ha	• Forest had regrown over 11 years to a basal area of 15 m^2/ha	• Considerable damage at the time due to careless placement of skid roads			Johns, A. 1991
Brazil, Amazon	• Amazon floodplain • Selective logging in high density *Virola* stands • Logging of *Virola* destined to be a short-lived activity in the Rio Preto basin		• Estimated that 145 m^3/ha of *Virola* are removed with current logging operations	• First logging started with removal of larger trees (dbh >45 cm) for plywood production, followed successive logging by saw millers removing material <30 cm dbh • Minimum felling limit for *Virola* supposed to be 45 cm dbh • After 5 years of logging the understorey consisted of a dense secondary community dominated by vines and herbs • *Virola* basal area plummeted from 24.6 m^2/ha to 2.3 m^2/ha after the first year of logging, and over a 5-year period seedling density per m^2 declined from 2.3 (year 0) to 0 (year 5)				Macedo, D. & Anderson, A. 1993
Brazil, Amazon	• Amazon forest, clay soils and slopes 0-25%		• A 100% inventory of trees >50 cm dbh yielded 18.7 m^3/ha of commercial volume (12.5 m^3/ha plywood logs, 1.0 m^3/ha veneer logs, 5.2 m^3/ha saw logs, and 4.1 m^3/ha of non- commercial species)					Malinovski, J. 1996

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Brazil, Amazon	• Silvicultural treatments (e.g., climber cutting, crown liberation thinning) at 10-year intervals are prescribed in new regulations		• Average logging intensity of 40 m^3/ha recommended • Minimum cutting cycle of 20 years was initially accepted, although 30-40 years may be more realistic in practice					Silva, J. 1992
Brazil, Amazon	• Tapaajos Region, Central Amazon · volume increment was 1.6 m^3/ha/a in unlogged and 4.8 m^3/ha/a in logged forest							Silva *et al*. 1996
Brazil, Amazon	• Várzea forests (wet, flood areas) • Average tree diameter at stump height was 1.1 m, average height was 44.4 m and average log volume was 11.1 m^3 • Sustainable tropical forest management requires economically and environmentally acceptable harvesting practices		• 140 m^3/ha of all trees with dbh >20cm, but only 43 m^3/ha of potentially commercial species	• Estimated diameter of selected trees at least 50 cm • Stump height always above 1.5 m, but could be higher depending on the buttress	• Gap size after felling averaged 845 m^2, or twice that in the terra-firme forest			Stokes *et al*. 1997
Brazil, Amazon	• Paragominas region • Of all the options for economic development in the Amazon region, the selective harvest of valuable timber species on a rotational basis is one of the most ecologically sound • Fires set to control weeds in adjacent degraded pastures spread readily into and through poorly logged forests causing extensive damage, but fires reaching the edge of unexploited forests quickly die out (penetrate only a few metres) • Careless logging of a fire-resistant ecosystem changes it to a fire-prone ecosystem			• Although regeneration occurs rapidly without further disturbance, poorly done selective harvesting leaves the forest in an open, fuel-rich, fire-prone state				Uhl, C. & Buschbacher, R. 1985
Brazil, Amazon	• State of Para • Entering an era in which fire will be a dominant disturbance in rain forest regions		• Logging intensity in study area 50 m^3/ha	• Woody debris input exceeded 150 m^3/ha due to careless logging • The opening up of the canopy (>50% gap area) allows the fuel to dry during the dry season to a point that it will burn (e.g., 5-6 rainless days)				Uhl, C. & Kauffman, J. 1990

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Brazil, Amazon	• Paragominas region of the State of Para • Terra firme forest with about 100 trees species/ha (>10 cm dbh), 25-35 m tall, basal area 20-30 m^2/ha and above ground biomass of 250-300 t/ha • Brazilian forests normally only have 5-20% of their area in a gapped condition at any one time • Severe damage to mid-size trees (20-50 cm dbh) caused by careless logging, and elevated probability of windfall and ground fires in these logged stands, suggests relatively long rotation times of 75 to 100 years before the next crop can be harvested • In reality once loggers provide access to the Para forest, ranchers and land-hungry settlers follow close behind foreclosing the possibility of future timber harvests • Structural reforms in regulation, enforcement and forest tenure are required to halt the reckless use of the forest timber resources in the Amazon		• Logging intensity typically 30-50 m^3/ha (4-8 trees/ha or 1-2% of all tree stems >10 cm dbh) of 30-60 species • First study area 52 m^3/ha extracted (1.7% of all trees >10 cm dbh) • Second study area (52 ha) • Logging intensity 31 m^3/ha (4.3 trees/ha)		• 700 m of tractor trail in the 6.8 ha area or 13 m/ha • 178 m/ha of tractor trail and 8% of total area was scarred (some places >20%) • Primary trail were 12 m wide and 1670 m were built (32 m/ha); secondary trails 3 m wide and 5380 m built (103 m/ha); tertiary trails 2.2 m wide and 2180 m built (42 m/ha) • 26% of all trees existing prior to harvest are killed or severely damaged (12% lost their crowns, 11% were uprooted by bulldozing, 3% had severe bark damage which may eventually lead to mortality) • 16% of the stand basal area was extracted, while an additional 28% was destroyed or severely damaged • Forest canopy cover was reduced from 80% to 43% • Removal of only 3-5 m^2/ha resulted in 34% reduction in basal area (usually 20-30 m^2/ha in pre-harvested stands)			Uhl, C. & Viera, I. 1989
Brazil, Amazon	• Tailandia • 2-3 m^3 of logs required to produce		• Average 2 trees/ha (16 m^3/ha) were extracted in three	• 0.37 trees/ha were not extracted due to defect (usually rot)	• On average 56 m of logging road were constructed			Uhl *et al.* 1991

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	1 m^3 of sawn wood • 15 months after logging had ceased, logging openings contained an average 63 seedlings of timber species • An average 127 m^3/ha of harvestable wood was present in the logged stands, which were then often burnt by colonists to create farms		study area (each about 16 ha) • 16 m^3/ha extracted + 3 m^3/ha felled but left + 18.6 m^3/ha destroyed = 37.6 m^3/ha bole volume loss		for each tree harvested · on average 5.8% of the area was cleared to establish logging roads and landings • On average 126 m^2 of forest were cleared next to each cut tree to allow room for the equipment to manoeuvre • 52 trees/ha (dbh >10 cm) were damaged or 26 trees/tree extracted • Half the trees damaged were in gaps, while the other half were on roads and landings .loss of canopy cover averaged 8.1% • 1.2 m^3 of wood was destroyed for each m^3 harvested			
Brazil, Amazon	• In the Amazon, as elsewhere in humid tropics, timber extraction is done carelessly and has significant impacts on forests, leading to severe canopy loss, increased likelihood of fire, and vine and grass invasion • Timber is undervalued and thus used carelessly • Sawmill yield is only 33% of each harvested log, but could easily be increased to 50% through simple improvements to equipment maintenance and worker training • By increasing logging efficiency, forest management and processing efficiency, companies would only need a third of the forest land they require now for the same sawn wood output		• Logging intensity of traditional small-scale logging in Várzea and terra firme forests is 1-3 trees/ha · logging intensity of larger high impact logging is 5-10 trees/ha • Logging in Para State covers about 4000 km^2 annually to produce about 8 million m^3 = 20 m^3/ha logging intensity • With RIL the cutting cycle can be 30-40 years, otherwise it will need to be 70-100 years			• One or more trees per hectare (amounting to almost 7 m^3/ha) are felled but never recovered by the skidder operation • Trained loggers were able to achieve a 3 times reduction in waste associated with felling and bucking (cuts closer to ground and reduced butt splitting)	• Machine operating time reduced by 20% • Cost associated with extra inventories, mapping and vine cutting is about US$50/ha • Cost savings from more efficient use of equipment and better wood utilization could be greater than the planning cost	Uhl *et al.* 1997

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Brazil, Amazon	• Paragominas • 238 sawmills studied with a lumber yield of 47% (2.13 m^3 round wood per 1 m^3 of sawn wood) • Natural tree falls in region open gaps 150-300 m • Early 1970s only a few high-value species harvested and forest impacts were small • 20 years later more than 100 tree species harvested • Annual dbh growth of 0.8 cm/a in managed stands (vine cutting and thinning), and 0.3 cm/a in unmanaged stands • Just considering commercial species the increased yield in managed stands after 35 years is 22 m^3/ha • Management cost would be about US$5/$m^3$ extracted, but loggers only pay stumpage of US$1-3/$m^3$ extracted		• On 3 sites average logging intensity was 6 trees/ha or 38 m^3/ha (range from 2.9-9.3 trees/ha and 18-62 m^3/ha) • Typical logging intensities range from 20-50 m/ha		• Opening about 40 m (218 m^2 of scraped ground surface per tree harvested) of logging road and 663 m^2 of canopy opening per tree harvested. • 27 trees (dbh >10 cm) were severely damaged for each tree harvested (150 trees/ha damaged), 48% uprooted, 41% broken stem, 11% severe bark damage • Tree damage did not increase in direct proportion with logging intensity (e.g., 18 m^3 extracted in area 1 damaged 5 m^2 of basal area, while in area 3, 3 times more wood extracted but basal area damage increased only 50% (7.5 m^2)			Verissimo *et al*. 1992
Brazil, Amazon	• Mahogany extraction • One band sawmill will on average produce 4500 m^3/a of mahogany sawn wood from 9900 m^3 of round wood (45.5% yield) • After logging there is a growing trend to convert forests to cattle pastures		• On average 5 m^3/ha of mahogany extracted (1 tree/ha) • The logging cycle for mahogany may be as long as 80-100 years when relying on natural regeneration	• Future mahogany cuts are in doubt; only 0.25 mahogany tree/ha of at least 30 cm dbh found on recently logged sites and no trees between 10-30 cm dbh (mahogany seedlings were also rare) • After mahogany logging volume still remaining was 31.3 m^3/ha of sawable wood, 13.1 m^3/ha in the potential use category, and 51.3 m^3/ha without wood-related uses	• About 1100 m^2 of forest ground was scraped clean or trampled for each mahogany tree extracted • 31 trees (dbh>10 cm) were severely damaged for each mahogany tree extracted			Verissimo *et al*. 1995

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Brazil (Amazon)	• This study is a follow-up to a previous study in this series (Winkler 1997). • Both studies were undertaken in a managed natural forest near Itacoatiara, in the Amazon region of Brazil. The two studies were conducted in collaboration with precious Woods Amazon (PWA). • The purpose of this re-examination was to assess the condition of the forest four years after logging had been completed. • Assessments were undertaken of regeneration within felling gaps and on skid trails, water infiltration rates on skid trails, the current status of potential crop trees and the condition of residual trees of commercial species. • Two plots, one treated with "conventional" logging techniques and the other with "environmentally sound" harvesting system were examined.							Wellhofer, S. 2002
Brazil, Amazon	• Test of environmentally sound forest harvesting. Detailed inventory, mapping and climber cutting 2 years in advance of cutting work studies showed that felling productivity did not decrease with the planned changes from traditional logging • In traditional logging a crawler tractor or skidder have no plan and drive throughout the stand searching for logs		• Logging intensity 35-40 m^3/ha (about half of the average harvestable volume of commercial species per hectare) • Logging cycle of 25 years	• 71.7% of potential crop trees undamaged	• 100 m spacing between skid trails planned • In RIL areas the skid trails were 3.5 m wide, 1200 m in length and covered 4200 m^2 • Traditional skid trails 4.98 m wide, 2646 m in length and covered 13177 m^2 • In RIL area roads, skid trails and landings covered 4.5% of area • In traditional logging area roads, skid trails and landings covered 14.4% of area • Average gap opening 124.7 m^2 • In RIL, felling and bucking losses			Winkler, N. 1997

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					were 3.9% of utilizable stem volume, while in traditional logging it was 8.5%			
Brazil, Eastern Amazon	• Paper outlines RIL in detail and improvements possible • With the implementation of RIL authors feel overall profits will be increased based solely on the short-term costs		• With planned harvesting subsequent logging intensities will be the same as the first (38 m^3/ha) on a 30-year cycle, while in unplanned harvesting it is estimated to be 17 m^3/ha on a 30-year cycle		• For each commercial tree felled, unplanned logging damaged 16 more trees with dbh >10 cm and affected a ground area that was 100 m^2 greater than in planned logging operations Unplanned vs. planned • = severe crown damage 7.4 vs. 4.5 trees/tree felled; • = trees smashed to the ground 7.2 vs. 4.9 trees/tree felled			Johns *et al.* 1996
Brazil	• Research on RIL in select tropical forest regions has demonstrated clear ecological benefits relative to conventional logging (CL) practices while the financial competitive-ness of RIL is less conclusive. • We conduct a comparative analysis of financial returns to one and two cutting-cycle logging entries for representative RIL and CL operations of the eastern Amazon.						• Despite the perceived investment risks, RIL harvesting operations generate competitive or superior returns relative to CL for a wide range of discount rates due to gains in harvest efficiency and forest conservation.	Boltz, F., Carter, D., Holmes, T. & Pereira Jr., R. 2001
Brazil			• Two scenarios are studied, one with reduced impact logging (RIL) and sparing of reserves without silvicultural follow-up in a 100-year cycle option needing four times as much land as the 25-year cycle option.				• A cash flow analysis over the 100-year period for both options with an 8% discount rate shows that the total costs on the land-intensive option (25 years) with silviculture are considerably less than in the land-	De Graaf, N., Filius, A., Huesa Santos, A. 2003

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							extensive option; the lower cost of infrastructure, log transportation and land acquisition offset the cost of silviculture. • Because the annual revenues from timber sale are the same in both options, the NPV of the intensive option is also much higher. • A sensitivity analysis shows that the land-intensive option is expected to give still a positive NPV in less favourable situations.	
Brazil	• In eastern Amazonia permanent plot studies, forest fuel moisture measurements, and hemispheric canopy photographs were used to study the impacts of fire on a selectively logged forest, the microclimatic conditions that foster forest fires, and the measures that loggers might take to reduce fire incidence. • In a recently logged forest, large logging gaps (>700 m^2) reached fire susceptibility after 6 days and medium sized logging gaps (≈200 – 700 m^2) reached fires susceptibility after 15 days. • Special low-impact logging techniques remove the same amount of timber as do the more typical high impact logging techniques, but fire is significantly less likely because the more careful operation avoids the creation of large logging gaps, the most fire susceptible areas.			• In large logging gaps the density of regenerating pioneer species increased by >60% in burned plots 15 months after the fire, while it decreased by >40% in unburned plots.	• Significant tree mortality followed a typical ground fire in a selectively logged forest. • Forty-four percent of all trees ≥ 10 cm in diameter at breast height died in a burned plot while only 3% died in an unburned plot.			Holdsworth, A. & Uhl, C. 1996
Brazil	• Indicators of financial performance for three case studies in the Brazilian Amazon are compared. • Case study results were disaggregated into common	• RIL investments in inventory, planning, vine cutting and				• At Fazenda Cauaxi, CL operations wasted 4.08m^3/ha and	• CL sawyers were 10 to 22 percent more productive in volume produced per hour (m^3/hr)	Holmes, T.P., Boltz, F. & Carter, D. 2002

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	measures of productivity, cost and profitability. • The Case Studies used were 1. Agrosete: The RIL-CL comparison was conducted on private forestland of Fazenda Agrosete, approximately 20 km southeast of Paragominas, Pará, Brazil. RIL was conducted on a 105-ha plot and CL on an adjacent 75-ha plot. 2. Cauaxi: Research was conducted on private forestland of the CIKEL timber company of Fazenda Cauaxi, some 120 km southwest of Paragominas, Brazil. 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 on an adjacent 100-ha plot. 3. Itacoatiara: The study examined private forestland of Mil Madeireira Itacoatiara S.A., a Brazilian subsidiary of Precious Woods, Ltd., which is located 227 km east of Manaus. Efficiency and environmental impact studies were conducted in two adjacent 10-ha cutting blocks.	infrastructure development up to a year before logging increases the proportional cost of pre-harvest operations				RIL operations wasted 1.32 m^3/ha. • At Fazenda Agrosete, CL (RIL) operations wasted 8.83 m^3/ha (0.40 m^3/ha) in the forest. • At Mil Madeireira Itacoatiara, CL (RIL) operations wasted 2.99 m^3/ha (1.31 m^3/ha)	than comparable RIL-felling teams. • Skidding operations are more productive under RIL. • RIL utilizing rubber-tyre skidders increased productivity by 41 to 49 percent over CL bulldozer operations. • 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. • RIL training costs comprise 1 to 18 percent of total harvest cost for CL and RIL operations. • RIL direct costs [16] (in US$/ m^3) ranged from 3 percent lower to 34 percent higher than CL direct costs. • When direct and indirect waste costs	

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							are accounted for, RIL net revenues are 18 percent to 35 percent greater than CL net revenues	
Brazil	• A comparison of costs and revenues was made for typical RIL and CL operations in the eastern Amazon. • An economic engineering approach was used to estimate standardised productivity and cost parameters. • Detailed data on productivity, harvest volume, wasted wood and damage to the residual stand were collected from operational scale harvest blocks. • Productivity and cost data were also collected using surveys of forest products firms.						• RIL was less costly, and more profitable, than CL under the conditions observed at the eastern Amazon study site. • Full cost accounting methods were introduced to capture the direct and indirect costs associated with wasted wood. • The impact of wasted wood on effective stumpage price provided the largest gain to RIL. • Large gains attributable to RIL technology were also observed in skidding and log deck productivity. • In addition, investment in RIL yielded an "environmental dividend" in terms of reduced damage to trees in the residual stand and reduction of the amount of ground area disturbed by heavy machinery.	Holmes, T., Blate, G., Zweede, J. Pereira Jr., R., Barreto, P., Boltz, F. & Bauch, R. 2002
Brazil	• This article examines the planning undertaken within the context of the ITTO funded project 'Integrated sustainable development of the Western Amazon based on resources'. • Three levels of harvesting are proposed and local people will be							Munoz-Braz, E. & d'Oliveira, M.V.N. 1996

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	trained to carry out the harvests. • The first two levels will prepare them to consider the logistical, technical, social and economic implications of the third level.							
Brazil	• Ground and canopy damage and recovery following conventional logging (CL) and reduced impact logging (RIL) of moist tropical forest in the eastern Amazon of Brazil. • Paired conventional and RIL blocks were selectively logged in 1996 and 1998.		• Harvest intensity was approximately 23 m^3/ha.		• Ground damage in the CL treatments occupied 8.9-11.2% of the total operational area as compared with 4.6-4.8% for RIL. • Blocks logged in 1998 had integrated canopy gap fractions of 21.6 and 10.9% of total area for CL and RIL blocks respectively. • Blocks logged in 1996 had 16.5 and 4.9% gap fraction for CL and RIL blocks respectively.			Pereira Jr., R., Zweede, J. Asner, G. & Keller, M. 2002
Brazil and Bolivia	• Many companies in Bolivia and Brazil have made substantial progress toward the adoption of RIL practices between 1995 and 2000. • In general, these companies have adopted the RIL elements that increase efficiency, reduce costs, improve marketing and enable companies to comply with the law. • Still lacking is implementation of the RIL elements that particularly benefit the forest, including directional felling and skid trail layout to protect future crop trees, minimal impact skidding and watercourse protection. • Many factors influence the degree to which companies are adopting specific RIL elements and these differ somewhat between Brazil and Bolivia. • In Bolivia, improving market access by becoming certified is probably the most important							Blate, G.M., Putz, F. & Zweede, J. 2002

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	reason why companies have adopted many RIL practices. • In Brazil, the most important factor driving RIL adoption has been the increased efficiency and cost savings derived from the adoption of the planning elements of RIL.							
Cameroon	• Littoral zone		• 1.05 trees/ha (dbh > 80 cm) extracted over a region of 474 km^2 (range 0.1-4.0 trees/ha)	• Mean gap size 400 m^2 (n=100) with damage or death to 5.2 adjacent trees >25 m tall, and 6.2 trees between 15-25 m tall • Less than 5% of trees had lianas	• Logging disturbance affects 8.4% of the area · 45.3 +/- 14.7 m of tractor trail per tree extracted • In 47 407 ha area 0.8% was compacted roadbed, 1.8% was road shoulder, 1.5% was trails and 4.2% was tree fall gaps (total 8.3%)			Bullock, S. 1980
Cameroon (Dimako)			• Harvesting intensities of >1 tree/ha on a 30 year cutting cycle recommended					Durrieu de Madron, L. & Forni, E. 1997
Cameroon (Dimako)	• Harvesting intensities of 0.5-1 tree/ha (5-15 m^3/ha) • A sufficient number of seed trees must be retained to provide for regeneration and biodiversity.		• Maximal harvesting intensity (A.P.I. de Dimako) was increased from 0.8 trees/ha (10m^3/ha) to 3 trees/ha (40 m^3/ha)		• Approximately 3% of the site is damaged during skidding operations • Main and secondary roads affect 1-2% of the area.	• Approximately 25% of the felled volume is left behind as waste or due to oversight.	• Governments should provide economic incentives for the implementation of RIL techniques	Durrieu de Madron, L., Forni, E. & Mekok, M. 1998
Cameroon (south)	• The study area is located on poor soils on the Central African Shield • The basal area is 34 m^2/ha		• The felling intensity ranges from 0.3 to 1.8 trees/ha	• The volume delivered to the sawmill was 70% of the amount felled	• 5.1% of the harvested area was disturbed (felling 1.4%, skidding 1.1%, road and landing construction 2.7%) • 30% of the damage due to roads and landings and 20% of the skidding damage could have been avoided	• Losses occurred during felling (21%), topping (7-10%), logs not found (4%) and cutting off both ends of the log to give the timber a better appearance (4%)	• Skidding restrictions following rain also reduced damage, but leads to losses of output in all production phases which may outweigh the benefits	Jonkers, W.B.J. & van Leersum, G.J.R. 2000

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					• Liana cutting did not have a noticeable effect on logging damage • Using the full range of RIL, damage to the residual stand could be reduced from 5 to 4%			
Cameroon	• The Tropenbos Cameroon Program (TCP) together with ITTO commenced a program in 1994: 'Development of methods and strategies for sustainable management of moist tropical forest in Cameroon'. • The study was conducted about 80 km east of Kribi in South Cameroon.	• Results indicated that improved planning, training and control could substantially reduce the area disturbed by skid trails and landings.		• Approximately 15% of harvestable timber was not harvested in the Wijma concession and only 70% of timber felled was actually delivered to the sawmill.	• Construction of roads and tracks should be avoided or minimized on slopes steeper than 10o to prevent excessive erosion. • Liana cutting before logging did not reduce the size of canopy gaps.	• Income could be increased by reducing waste.		Foahom, B., Jonkers, W.B.J. & Schmidt, P. 2001
Cameroon	• In the lowland rain forest in southern Cameroon, an experiment was set-up to test whether pre-felling climber cutting could reduce logging damage. • The abundance of lianas in the forest and their resprouting capacity after cutting was assessed. • Logging damage was considered as tree mortality and tree damage in the felling gaps and the sizes of the creates gaps after felling.		• The average harvest level in the study area was one tree or about 13 m^3 ha -1.	• Lianas were very abundant: on average nearly 5000 individuals (at breast height) of which over 100 large ones (≥5 cm DBH) per ha. • Some 70% of monitored lianas had died 22 months after cutting. • Resprouting capacity was high but variable among species.	• Felling gap sizes (average 550 m^2 per felled tree), tree mortality (12 trees per felled tree) and damage (20 trees per felled tree) were not significantly affected by pre-felling climber cutting. • A minority of the damage was severe. ▪ Smaller trees were most prone to destruction and severe damage. • The results show that pre-felling climber cutting has no significant effect on resulting gap-sizes, tree mortality and damage levels.			Parren, Marc & Bongers, F. 2001

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Canada	• A 7-year monitoring study was established to evaluate the effects of careful logging on vegetation development in the southern boreal forest of Quebec. • A total of 255 sample plots (2 m^2) were located in seven cutovers in predominantly black spruce (*Picea mariana*) forests that were whole-tree "careful logged": 120 on fresh to moist silty clays or silty clay loams and 135 on dry to fresh loamy sands. • Three microsites were sampled: skid trails and the edge and the centre of protection strips.			• Softwood stocking 7 years after harvest after harvest (based on 2- m^2 plots), ranged from 69 to 74% on sites.	• A gradient of disturbance from the skid trail to centre of the protection strip was evident for finer textured sites. • Higher disturbance levels in skid trails favoured establishment of larch, raspberry and graminoids.			Harvey, Brian & Brais, S. 2002
Central Africa	• Field report of visit to two timber concessions in central Africa: CIB (Société Congolaise Industielle des Bois) and SBL (Société des Bois de Lastoursville). • Both CIB and SBL are at an early stage in the process of developing comprehensive forest management plans for their timber concessions.	• Inventories will be carried out on a 1% sampling basis by both companies. • Regeneration surveys will be done at a lower sampling rate.				• Conversion ratios for both companies' sawmills average around 30%.		Dykstra, D., Toupin, R. & Othman, M. 2001
Central Africa	• A comparison between unlogged, 6-month and 18-year post-harvests forest stands indicates lasting effects of highly selective, high grade logging. • A better approach to manage timber zones for timber production and conservation would be an adaptive management approach based on increased species selection and canopy disturbance. • Zones targeting the conservation of closed forest obligate species should not be logged.			• Stem densities of both saplings and trees in unlogged forest were significantly higher than those in forest sampled 18 years after logging. • Evidence suggests inadequate recruitment of *Entandrophragma cylindricum* and *E. utile*, the principal timber species. • There will also be an abundance of other top quality timber species remaining after selective removal of African mahogany.				Hall, J.S., Harris, D.J., Medjibe, V. & Ashton, P.M.S. (in press)
Central America	• Generally 400 trees/ha with dbh >10 cm, and 40 trees/ha with dbh >50 cm • Can be 100-150 species/ha and with increasing wood scarcities			• Loggers paid based on the volume removed, therefore they only take out the best and largest logs			• Cost of detailed inventory for CATIE (RIL) is US$27/ha	Quirós *et al.* 1997

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	previously unutilized species are being increasingly logged • Lack of planning and control in logging operations and government paperwork and policies lead to illegal logging • Lack of integration between logging and the timber using industry, thus the industry has little incentive to control how logging is done			• This results in 20-25% of the cut volume not being extracted due to felling damage or poor quality • This type of material is suitable for supplying local markets through small-scale sawmilling				
Congo	• The study was carried out in a closed-canopy, broad-leaved forest located in southern Congo at the border to Gabon • An Inventory revealed an average density of 455 trees/ha of which 3.3% is Okoume (*Aucoumea klaineana*) • The average density of harvestable trees in the study area is less than one tree per hectare • The harvestable volume (80cm dbh) of Okoume is 11.8 m^3/ha (total volume of Okoume 37.5 m^3/ha)		• Harvesting intensity 5.8 m^3 (1 tree per hectare, target diameter 80cm dbh)	• The total recovery, expressed as net log volume compared to the standing stem volume (including stump, up to the first branch of the crown) is 70% • The average wood recovery rate is 86% after felling and 70% after crosscutting.	• Soil disturbance was recorded on 8.4% of the total area. Felling sites accounted for 3.8%, skid trails for 2.7%, secondary roads for 1.0%, primary roads for 0.7% and landings for an estimated 0.2% • The damage frequency for all species and size classes is 6.3% (17.7 damaged trees per felled tree) • The overall damage frequency for Okoume in all diameter classes is 7.2% and of those trees 40-80 cm dbh (immature future crop trees) it is 9%	• The loss of 14% of the volume during felling is in stump wood and in stem wood that does not meet quality requirements (stump wood is not considered usable).		FAO 1997a
Congo, Republic of	• Three 50 ha harvesting compartments studied • Under the prevailing conditions the observed forest operation could be called "low impact" since only 1 tree/ha was removed		• Average logging intensity 1 tree/ha or 5-6 m^3/ha • Average 455 trees/ha with dbh >10 cm • All Okoumé trees >80 cm dbh extracted	• Extracted log recovery was 70% of stem volume (includes stump and stem volume up to the first branch of the crown)	• Average skidding distance 403 m (crawler tractors used for short hauls and concentrating logs, while wheeled skidders used for the long haul to the landing) • A total of 8.4% of			Scharpenberg, R. 1998

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					the area had soil disturbance (felling sites 3.8%, skid trails 2.7%, secondary roads 1.0% and primary roads 0.7%) • Of the 8.4%, 0.8% was seriously disturbed skid trails and landings and 5.8% was slightly disturbed. on average 17.7 trees per tree felled (3 trees per m^3 extracted) were damaged during felling • The average number of skidding damaged trees was 11.8 per tree felled (11.5/ha or 212 trees/km of skid trail) • In total 29 trees/ha were damaged during logging (30 damaged trees/tree felled or 5 damaged trees/m^3)			
Costa Rica	• This study was carried out in the natural forests of Costa Rica • A polycyclic system was established in order to maintain irregular structure and species diversity		• The harvesting intensity for the first harvest in natural forests ranges from 40 to 60 m^3/ha • Secondary forests are managed on a 15 year cutting cycle with a harvesting intensity of 20 to 30 m^3/ha	• Up to 60% of the commercial volume may be extracted with a minimum harvesting diameter of 60cm dbh			• Additional costs are associated with the implementation of RIL ("buen manejo forestal") techniques	BOLFOR, IURFO & CIFOR 1997
Costa Rica			• Logging intensity was 6 trees/ha in oxen logged area and 7.33 trees/ha in tractor logged area	• In oxen logged area 1.3% of original stems extracted, 11.8% very severe injury or killed, 3.2% severe injury, 12.4% minor injury, 68.5% had no injury, and non-logging				Cordero, W. & Howard, A. 1996

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
				damage was 2.8% • In tractor logged area 4.8% of original stems extracted, 19.2% very severe injury or killed, 0.9% severe injury, 14.1% minor injury, 60.7% had no injury, and non-logging damage was 5.3%				
Costa Rica	• Montane forest • Mean annual rate of mortality in unlogged forest was 2.2% (2.1% for 10-30 cm dbh trees, 2.8% for >30 cm dbh trees) • In lowland tropical forests the annual mortality rate ranges from 1-3%							Matelson *et al*. 1995
Costa Rica	• The commercial volume ranges from 90 to 1712 m^3/ha						• With a total sales price of US$ 80.39, the planning process accounts for costs of US$ 2.99/m^3 • The total management costs are US$ 129.58/m^3 • Average labour costs are US$ 2.39/m^3	Muñoz, R.R. 1997
Costa Rica	• This study was conducted in the Atlantic lowlands of northeast Costa Rica (poorly drained swamp forest) to evaluate a selective logging system		• Harvesting was limited to trees of at least 70cm dbh, 10cm above the legal limit in Costa Rica • Extraction intensity averaged 6.3 trees/ha for 28ha and 45.8 m^3/ha for a 7 ha sub-sample	• Felling, immediate residual mortality and skid trail construction reduced the basal area by 18.3% • Canopy cover averaged 91.4% in undisturbed plots and 73.4% in logged forest. • The relationship between extraction intensity and post-logging canopy cover was linear	• Skid trails covered 4% of the area · 17.6% of the residual stand was killed or damaged during logging (12.4% damaged, 5.2% killed) • Severe damage (trunk snapped or uprooting) usually did not occur to trees >50cm dbh • Moderate damage types (canopy damage, bark removal) were relatively more frequent in size classes of >40cm dbh		• Logging gaps with a low commercial value can comprise a substantial proportion of improperly managed forests	Webb, E.L. 1997

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					• The relative level of damage during controlled logging did not appear to deviate substantially from uncontrolled logging operations			
Côte d'Ivoire	• Productivity restored 9 years after logging and with the protection from brush fires the number of new stems increase 2.3-2.5 fold • Increase in productivity from 1-1.5 m^3/ha/a to 2-3 m^3/ha/a (regions 700 mm rain per year) and 3-3.5 m^3/ha/a (regions up to 1500 mm rainfall per year)							Catinot, R. 1994
Costa Rica	• Compatibility of different commercial uses of a montane tropical oak-bamboo forest in Costa Rica was assessed for selective logging and harvesting of non-vascular pendant epiphytes. • Nine years after selective logging no negative impacts were detected on the biomass of these epiphytes at 1-3m range (the heights at which they are harvested).							Romero, C. 1999.
Costa Rica	• The study was conducted in the Cordillera de Talamanca, Costa Rica, at the Villa Mills experimental site administered by CATIE. • Jan 1991 – July 1992, controlled logging applied to 21 ha. • Area divided into nine 1 ha plots, separated by 20-25 m wide buffer strips. • Two logging treatments were randomly assigned to 4 replicate plots per treatment (total of 8 plots), plus a single control plot. • Height and diameter growth were assessed 5 years after logging along with individual survivorship of juveniles. • Target species – *Quercus costaricensis, Q. copeyensis, Drymis granadensis, Ocotea austinii, Weinmania pinnata*.		• The treatments consisted of extracting 20 (light) and 30% (moderate) of the stand basal area (stems ≥ 10 cm DBH).		• For seedlings, the overall 5-year mortality rate (exponential model) was significantly higher under the lightest harvest intensity while for saplings, no significant differences in mortality were detected among harvesting intensities.			Saenz, G. & Guariguata, M. 2001

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Democratic Republic of Congo			• Yield of exportable species is limited for marketing and ecological reasons to 6-10 m^3/ha on a 25-year cycle, where the forests have already been selectively cut • On newer concessions logging intensity can be expected to be 20-22 m^3/ha • If all species currently used by foreign and home markets are taken into consideration the yield could be 50 m^3/ha					Kelvin, A. 1993
Ecuador	• Tropical forests • Most common skidding equipment is large rubber-tired skidders • Safety is more or less disregarded • No communication between sawyers and skidder operators	• Through better planning and control of logging operations, increased productivity and reduced maintenance and repair cost would cover the planning and control costs, as well as inventory holding costs for the approx. five months of shutdown time required • Preplanned skid trails and directional felling can reduce the area covered by skid trails to 15% • If only advanced planning of skid trails and			• With haphazard operations 40% of ground surface area disturbed · in wet soil conditions bulldozers dig out trails to mineral soil to a depth of 0.25-0.5 m • On slopes over 10% trails are dug out even deeper in hope of getting better traction · in wet conditions damage is amplified and up to 75% of area can be covered by skid trails (trails used until troughs of mud 1 m or more in depth) • By confining skidders to skid trails and using the winch more, skid trails could be reduced to 4% of area		• When operating in wet conditions one company experienced a 100% increase in machine maintenance and repair cost, and productivity was only 15% of that in dry conditions· loggers receive no formal training in felling or bucking • With the use of proper felling and bucking techniques a 15-30% increase in wood volume at the mill could be realized	DeBonis, J. 1986

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
		wet-weather shutdown were implemented, most of the current skidding damage could be eliminated						
Fiji	• The local forest owners were capable of applying the prescribed activities. Tree selection was mainly based on silvicultural and ecological criteria.		• The harvesting intensity for RIL was 38.7% of the initial volume. With CL 81.6% of the volume were harvested					De Vletter, J. & Mussong, M. 1995
Fiji			• Logging intensity 40-50 m^3/ha (>35 cm dbh), from a total wood biomass estimated to be 250 m^3/ha		• 62% of area disturbed (45% light disturbance; heavy disturbance, skid tracks and skid roads 12%; landings and roads 5%)			Margules *et al.* 1987
Fiji	• The most favourable management concepts are *High Impact* and *Medium Impact Logging*. These options also ensure that non-timber forest products can be produced on a sustainable basis • For minimum risk, the ML option seems to be most favourable.		• CL: harvesting intensity <80% of volume of trees >35cm dbh (cutting cycle 45 years) • RIL: harvesting intensity 15 [LL], 35[ML] and 55% [HL] of volume of trees >35cm dbh (cutting cycle 10, 15 and 30 years respectively)				• CL: overall harvesting costs US$ 39.08/m^3 • RIL: overall harvesting costs US$ 37.52 to 41.24 /m^3 • Revenue: CL -2.52 US$/$m^3$, HL -0.10 US$/m^3, ML +0.74 US$/$m^3$, LL-1.16 US$/m^3	Mussong, M., Singh, K., Laqeretabua, J. & de Vletter, J. 1996
Fiji	• Study of two logging concessions with mixed tropical hardwoods • Payment rate based on production results in excessive logging damage, improper log bucking and other poor practices • 40 species utilized		• Stocking about 200 m^3/ha of which 50 m^3/ha is merchantable wood above the minimum felling limit of 35 cm dbh		• Surveys of the logging areas indicated that soil disturbance was moderate, but acceptable			Sundberg, U. 1987
French Guiana	• Average volume in area (>10 cm dbh) 350 m^3/ha and basal area 31 m^2/ha		• Base treatment removes 33 m^3/ha (2.6 m^2/ha of BA)					Bariteau, M. & Geoffroy, J. 1989
Gabon	• Lowland tropical forest in the Lopé Reserve • In 1988 estimated that 46% of Gabon's forest had been selectively logged at least once, and each year about 2500 km^2 is		• Logging intensity 1-2 trees/ha using conventional logging with chain saw felling and crawler tractor extraction	• 26 trees >70 cm dbh felled, 23 extracted (2 missed and 1 was hollow), plus 5 killed during operations • Of the 175 stems dbh	• 2 trees >70 cm dbh killed during road construction • 1.4% of surface area covered by a major road, 5.0%			White, L. 1994

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	logged; 60% of which has not been previously logged • Extraction rates and damage levels in other parts of central Africa are similar due to the low logging intensity		• 70 cm minimum legal felling diameter for commercial exploitation • In 11.25 ha study area logging intensity 2 trees/ha	>70 cm 17.7% of stems and 20.6% of basal area removed (26 felled and 5 killed trees) · three trees >70 cm dbh killed during falling • For stems >10 cm dbh sample area 1.25 ha had 505 trees and 6 lianas • Basal area before logging 39.1 m^2/ha (408.8 stems/ha) and after logging 34.3 m^2/ha (364.8 stems/ha) • = 10.8% of stems lost, mostly due to incidental damage	covered by secondary extraction roads (6.4% of area bare and compacted) • 5.0% of surface area had skidder trails and 16.9% was covered by crowns of fallen trees • 71.7% of area was not physically altered by logging • On newer concessions logging intensity can be expected to be 20-22 m^3/ha • In adjacent area logged in 1986 roads covered 1.6% of site, skidder trails and secondary extraction roads made up 7.5% of site, and 51.2% of canopy suffered some disturbance • In adjacent area logged 10-15 years prior, roads accounted for 1.8% of area and skidder and secondary extraction trails 7.2% of area			
General					• On skid trails >15% side slope, blading causes excessive damage			Andrewartha, R. 1998
General	• Lesser known/utilized species • Danger in placing too much emphasis upon the development of new products and technology for lesser known species because it provides an excuse for not doing things properly today		• Logging intensity levels in southeast Asia and Latin America varies from 4 to 48 m^3/ha	• Final yield of product from a tree can be as lows as 10-20% and typically averages no more than 30%				Bethel, J. 1984

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
General	• Tropical moist forest		• A felling intensity of 5-8 trees/ha is considered to be sustainable for most types of tropical forests					Boerboom, J. & Wiersum, K. 1983
General	• Tropical secondary forests		• Wood production based on short-term measurements (1-2 years) are variable and range from 2-11 t/ha/a, which are greater than for mature tropical forests of 1-8 t/ha/a (all trees to 10 cm dbh)	• Factors to convert volume to wood biomass are 1.1 for dry and moist forests and 0.9 for wet forests (or biomass to volume 0.909 and 1.111, respectively)				Brown S. & Lugo, A. 1990
General	• Tropical rain forests • Conservation and management • Outlines advantages of RIL • Well-established knowledge from experience in temperate and tropical forestry that well-planned and executed timber harvesting costs less than haphazard and unskilled logging • Forest misuse and abuse remain rampant, over logging and underutilization persist in tropical forests and elsewhere		• With conventional logging (at least in Malaysia) future yields will be reduced to half or a third of the sustainable potential under proper selection felling systems • Harvest rates of 40-60 m^3/ha on a 25-year cycle as envisaged in Malaysia will certainly exceed the rates of replenishment of any of the nutrients • Lowering of felling limits to increase logging intensity must be avoided, should not be lower than 60 cm in dipterocarp forests • 30-60 m^3/ha removals on a >40 year cycle with RIL can be held as sustainable	• Over logging removes more than 50% and up to 80-90% of the canopy • Conventional selective logging as currently practised causes 70-80% damage to residuals, with only 10-20% of the basal area removed	• Conventional logging with crawler tractors 20-60% of the soil surface is loosened, moved or compacted • With excessive roading and skidding, and thus excessive compaction and erosion, felling cycles of 25-50 years are not sustainable, and 60-100 years is more realistic (even longer on poor soils)			Bruenig, E. 1996
General					• 15-35% of all residual trees damaged in polycyclic systems • 40-60% of all residual trees damaged in monocyclic systems			Bruijnzeel, L. 1992

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
General	• Fibre for virtually all pulp and paper and reconstituted panels can be derived from plantations and/or from heavily modified temperate forests • Tropical timber will increasingly change from a bulk commodity to an exclusive, high-value product for niche markets • Any interventions that reduce the commercial value of TMF will undermine the economic basis for their retention, thereby accelerating conversion to agriculture							Byron, N. & Perez, M. 1996
General	• Tropical moist forests • Smaller the volume logged the more elaborate and complete must the pre-harvest survey be				• Successful logging operations and a good network of trails depend essentially on a good pre-harvest survey		• Skidding operations represent 20-40% of the cost of wood delivered to roadside	Chauvin, H. 1976
General	• Implementing RIL can lead to a gain of as much as 50% in the "carbon storehouse" benefits from the remaining vegetation				• RIL: impacts to the soil from heavy logging machinery can be reduced by 25% • RIL: damage to advanced regeneration was reduced by 50% relative to CL			CIFOR 1998
General	• Amount of logging and mill residues generated in the tropics estimated to be 208 million m^3 or 89% of the total annual production of industrial round wood			• Estimated felling recovery rates • Africa 54% • Asia/Pacific 46% • Latin America and Caribbean 56% • total tropics 50% • Of all the industrial wood felled annually in the tropics 50% remains in the forest as unused residues			· Harvesting operations in natural tropical forests can reduce logging residues by 10-30% without a significant increase in harvesting cost	Dykstra, D. 1992
General	• Sufficient information exists to permit sustainable harvesting operations in virtually any area of tropical forest worldwide							Dykstra, D. & Heinrich, R. 1992
General				• Experience in training programmes to improve cross-cutting				Dykstra, D. & Heinrich, R. 1996

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
				skills suggests that improved utilization of 20% or more and increased log values of 10-50% can be attained				
General	• It may be preferable to reduce the rate at which new areas are logged by practising more intensive logging in areas currently being harvested.		• In selection systems, individual trees are selected for harvesting in order to sustain yield. In contrast, selective harvesting involves cutting selected trees based on economic considerations without respect to sustained yield		• Van Gardingen (1998) observed an absence of regeneration of dipterocarp seedlings on sites with disturbed soils and in large logging gaps • Tropical forests are resilient to disturbances on a much larger scale than those created by single treefalls. (Lugo 1995)			Fredericksen, T.S. 2000
General	• Low forest revenues can result either from low forest fees, set at levels well below the value of the timber, or from low collection rates, the result of inefficient collection systems.			• Low forest fees, which mean that timber is under priced • Encourage poor utilisation of timber in the forest and inefficiency in utilisation in processing industries.			• Economic incentives and better designed forest revenue systems can contribute to and support RIL. Higher prices and values of tropical timber would make improved forest management economically attractive.	Gray, J.A., 1997
General	• If the costs of implementing RIL are at a level acceptable to the industry, then RIL will be widely adopted.		• Harvesting intensities are highly sensitive to the spatial distribution of commercial stems	• Stable supplies of currently marketed timber species will only be enhanced in stands where RIL techniques are employed if the resulting level of disturbance is consistent with the regeneration requirements of the target timber species.	• The interaction between slope, soil and stem size will constrain the achievable environmental benefits without further technological and financial inputs.		• RIL will ultimately fail to produce the expected benefits when harvesting levels overshadow the gains made through careful planning • Differences in topographical, soil and hydrological conditions will alter the savings made by RIL when costs of environmental impacts are	Hammond, D.S., van der Hout, P., Roderick, J.Z., Marshall, G., Evans, J. & Cassells, D.S. 2000

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
							counted • RIL: The capital costs of equipment must be incorporated into the calculation of costs and benefits associated with better planning. • The spatial distribution of commercial trees has important effects on the expenses of foregone timber.	
General			• Possible action 13: the annual allowable cut (AAC) should be set conservatively in the case of absence of reliable data on regeneration and growth dynamics of tree species, especially in regard to diameter increment and response to the effect of logging on trees and soils					ITTO 1992a
General	• A certain level of RIL can be achieved simply through careful planning, scheduling and control of logging operations						• RIL cost US\$2.05/m^3 and logging cost saving of US\$2.47/m^3, resulting in an overall saving of US\$0.42/m^3 • Also would be a substantial long term increase in timber yield	ITTO 1996
General	• A logging operator with only a short-term lease will be concerned only with a single cut and will not be motivated to minimize environmental damage • Lack of financial interest in the future crop is probably the main reason for the excessive damage levels typical of short-term extraction operations • In most tropical forests, the most		• Harvesting intensity in tropical forests varies considerably from 1 to 72 trees/ha depending on the forest type and country • Malaysian dipterocarp forest average 14 trees/ha, but up to 72 trees/ha extracted • Most Amazonian terra					Johns, A. 1992

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	effective form of forest management is undoubtedly protection and encouragement of advanced growth in optimally sized gaps created during logging, with planting of gaps where no advanced growth exists		firme forests yield 3-5 trees/ha (10-15 m^3/ha) • Some African forests as lows as 1.1 trees/ha · in the 1980s 8.4-13.5 m^3/ha in neotropical and African forests • In Asian dipterocarp forests generally 50 m^3/ha and in Sabah up to 110 m^3/ha					
General	• Report on state of logging in the tropical moist forests (TMF) based on a literature review and site visits • TMF can be sustainably managed for timber and non-timber products, however, systems for sustained management of TMF are rarely implemented in practice • RIL methods are well known but not implemented • If a bulldozer is oversized there is a temptation for the operator to use power instead of skill, while if it is undersized too much winching and equipment manoeuvring, and thus increased cost and impact can result		• A compartment within a concession should be logged at one occasion and then closed off to allow the forest to recover: i.e., 30-40 years • Re-entry prior to the full logging cycle to harvest another species should be prohibited				• Theoretical simulations of cost and yield showed a 20% reduction in cost through improved logging practices, with 5 m^3/ha (7%) more volume (logging intensity 60 m^3/ha) could be extracted through improved felling and bucking techniques	Jonsson, T. & Lindgren, P. 1990
General	• Directional felling is done to minimize damage to the log and residual stand, and to facilitate log extraction • Direction felling is more time consuming than haphazard felling, but gains in these three areas will almost certainly outweigh the costs							Klassen, A. & Cedergren, J. 1996
General	• Sustainable management of tropical forests • Loggers are often ignorant and not aware of how the economy of their operations benefits from using more efficient and better adapted machines and work methods							Lindgren, P. 1992
General	• Tropical mixed forests • Growth of volume actually commercialized for mixed forests is between 0.1 and 0.5 m^3/ha/a		• Logging intensities in Latin America 8 m^3/ha/entry, Africa 13 m^3/ha/entry and Asia dipterocarp 40-100 m^3/ha/entry, and	• Common to find 40-70% of the advance growth destroyed in the harvesting process, leaving only 12-33 stems/ha for the				Masson, J. 1983

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
			overall average 37 m^3/ha/entry	next cut • Very heavy damage (70-100%) can be expected when basal area extracted rises about 12 m^2/ha				
General	• Tropical high forests · harvesting operations utilizing detailed planning cost 20-45% less than comparable operations with minimal planning • Found that better planning had better organization and supervision, fewer accidents, fewer merchantable trees left unfelled and few logs lost after felling							Mattsson-Marn, H. & Jonkers, W. 1982
General	• Tropical moist forests • The impact of tropical downpours causes substantially more soil erosion than anywhere else in the world, thus need to maintain cover • Need to have a cautious approach in the use of TMF							Myers, N. 1983
General	• Product yields that can be generally expected are: • sawn wood 56-68% • plywood 50% • wafer board 75-80% • strand board 85-90% • particleboard 90-95% • thin particleboard 100% • high density fibreboard 95% • medium density fibreboard 85-90% • plywood substitutes will result in better forest utilization							Niedermaier, P. 1984
General	• One of the many paradoxes of tropical forestry over the past 30 years is that the rise in public interest has been paralleled by a decline in the application of systematic management • Another paradox is that the same period has seen a great increase in research on tropical biology but little corresponding incorporation of research results into management practice • The absence of security and tenure discourage forest managers from investing time and		• Control of harvesting operations is the most important condition for sustainable management after the long-term security of the forest itself	• Re-entry - the return of loggers to take previously non commercial species or sizes, which was demonstrated to be highly damaging to regeneration more than 35 years ago • Is still a problem in many countries	• While the merits of various forest management systems are being debated, tropical silviculturalists are of one voice in advocating the use of RIL techniques			Palmer, J. & Synnott, T. 1992

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	money in management for future production and often led to such investments being lost							
General	• Ecological guidelines for the management of tropical moist forests • Management of natural forests is preferred over plantations · where options still exist, countries should attempt to derive the maximum of their timber needs from a managed "natural forest estate"				• Tropical soils are highly susceptible to degradation, particularly if they are physically disturbed or exposed to sun or the direct impact of heavy tropical rainfall			Poore, D. & Sayer, J. 1987
General	• It can not be assumed that timber production in tropical forests is feasible in a sustainable manner considering the ecological and socio-economic components of sustainable resource management						• RIL will increase the initial costs of harvesting operations and therefore reduce the land value and revenue at least on the short run	Pretzsch, J. 1997
General	• Commercially exploited forests are important components of local, regional and global conservation and development strategies							Putz, F. & Viana, V. 1996
General	• The success of selective silvicultural systems depends very much on the quantity and quality of the future crop trees left after logging • The logger makes or unmakes the next harvest in the same area • The growth rate of residual trees has been reported to be about 3.2 m^3/ha/a • Various research results listed range from 1.6 to 8.6 m^3/ha/a				• Width of logging roads varies from 5 to 10 m, with the right of way extending from the road centre-line up to 15 m on both sides of main roads, and 10 m for spur roads • In high lead settings damage to residuals due to felling was 23-28% and yarding damage was 4-6% • In tractor skidding felling damage to residuals was 9% and skidding damage 2% • The higher felling damage in the high lead setting is probably due to working on steep			Rapera, R. 1978

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					terrain (>40%), where felled trees tend to roll more and thus cause more damage to residuals			
General	• "Natural forest management" [NFM] can be categorised as a polycyclic felling system		• Cutting cycle of 25-40 years was applied · In the conversion phase of primary forests, a large volume of mature timber is harvested. In the subsequent phase a constant, smaller amount of wood is cut at regular intervals.	• CL: little attention is paid to the condition of the residual stand • CL is unsustainable, because the forest will not yield another harvest of the target species for a long time, if ever.	• Where the topography is flat and commercial trees occur at very low densities (<1 tree/ha harvested), CL is unlikely to cause excessive damages.		• Investments in [NFM] are financially unattractive and governments are generally unwilling or unable to force loggers to make such investments.	Reid, J.W. & Rice, R.E. 1997
General	• In management systems based on selective felling there are limits to harvesting intensity above which felling and skidding damage will be so high as to jeopardize the forest's regenerative capacity, no matter how well the operation is planned and executed • In many forests in South America many commercial species require small canopy openings, while in Asia and Africa heavier canopy opening is almost always desired • Increased harvesting of lesser used species can have both positive and negative impacts, depending on whether logging intensity is increased (thus jeopardizing the forest) or whether it offsets logging pressure on the more desired species		• 10 trees/ha has been quoted as the order of magnitude for the upper limit of logging intensity • However, it is impossible to set universal threshold values for logging intensity since logging intensity depends on damage to the remaining stand and acceptable damage limits vary according to the physical and biological characteristics of each forest					Reitbergen, S. & Poore, D. 1995
General	• Increasing the use of lesser used species is seen by many as the way of making natural forest management more viable • Harvesting more m^3/ha means that less area needs to be harvested and the forest generates more revenue							Sarre, A. 1995
General	• The single most important thing that foresters can change is the way that forests are logged • There is no doubt that most current logging techniques cause unnecessary damage to the forest							Sarre, A. 1996

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	• Better logging techniques will have an immediate positive effect on post-harvest value of the forest and will increase the long-term chance of sustainability							
General	• New technologies for transporting and converting heavy hardwoods have radically changed the situation • Plywood mills in the Amazon have already captured a major share of an international market where south-east Asia had previously expected to retain a long-term competitive advantage • Also new developments in composite wood products and pulping technologies							Sayer, J. & Byron, R. 1996
General	• Humid tropical forests • Low-impact logging techniques are not difficult to implement and may be cheaper than conventional logging practices		• Recommends logging cycles 20-40 years long with fewer trees extracted, rather than a very intensive cut every 70-80 years					Sayer *et al.* 1995
General	• Technologically there is no reason why plantations cannot supply most of the world's wood requirements by early next century • Demand for a few speciality products that can be obtained only from natural forests may not increase greatly, and can probably be satisfied from ecologically sensitive logging operations in areas where forests are retained primarily for their environmental and amenity functions • Expect the natural forests to become less able to compete with outputs of the rapidly expanding plantation sector in the tropics and subtropics • Increased use of RIL should lead to a reduction in environmental impacts and greater productivity in future cycles							Sayer *et al.* 1997
General	• Tropical rain forest management · plantations yield great benefits but cannot replace the functions of current natural forest areas, they are complementary with each one supplying different products and		• If residual crop trees are 10 cm dbh on average a minimum logging cycle of 40 years is required to get average 50 cm					Schmidt, R. 1987

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	most applicable to different types of terrain • Average dbh growth in natural tropical forests varies with many factors but is seldom greater than 1 cm/a and is often less		dbh • If larger trees can be released a shorter 25-30 year logging cycle could be possible • Brazil: inventory found 54 m^3/ha of stems >45 cm dbh, of which 36 m^3/ha were of 28 commercial species (study extraction produced 72 m^3/ha of which 64 m^3/ha were commercial) • Peru: the VAC started at 15 m^3/ha (15 commercial species), but has increased to 30 m^3/ha as 20 more species became commercially viable • Colombia: 114 m^3/ha of total stem volume and 33 m^3/ha of commercial volume • Suriname: CELOS system should get 40 m^3/ha on a 20 year logging cycle with 13.5 trees/ha being commercial • Africa: the net volume of logs extracted varies from 5 to 35 m^3/ha					
General	• Based on general considerations in different forests the annual growth potential can be estimated to be 1-2 m^3/ha/a for Africa, 1-3 m^3/ha/a for Latin America and 2-4 m^3/ha/a for Asia							Sommer, A. 1976
General	• Need to determine acceptable levels of increased logging intensity with harvesting of lesser used species before environmental damage is unacceptable • Where logging intensities are low the lesser used species are a good potential source of wood		Logging intensity • in many tropical American countries 8.4 m^3/ha • in many African countries 13.5 m^3/ha • Peninsular Malaysia 45 m^3/ha • Sarawak 75 m^3/ha • Sabah 90 m^3/ha • Philippines 90 m^3/ha	• Studies in Sabah have shown only 34% of residual stand undamaged				Yeom, F. 1984

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
General	• Effective RIL programs include elements of monitoring, auditing, and enforcement of rules, laws, regulations and guidelines. • There are a number of linkages between RIL and other necessary conditions for sustainable forest management. • The links only become apparent when examining the impediments to the adoption of RIL and in particular the effects that illegal logging has on profitability and decision making by forest concessionaires.							Durst, P. & Enters, T. 2001
General	• RIL has become associated with logging technologies that have been introduced into tropical forests explicitly for the purpose of reducing the environmental and social impacts associated with industrial timber harvesting. • This paper discusses the requirements for RIL and some of the impediments to its implementation in the tropics.							Dykstra, D. 2001
General	• RIL involves the application of technologies that have been known for many years and are utilized as a matter of common practice in many industrialized countries. • RIL requires both a new mindset and also a new approach to tropical forest management.							Dykstra, D. 2002
General	• RILSIM is a computer software package designed to permit users to rapidly estimate the cost and net revenue associated with logging operations so that they can compare short-term financial costs and returns expected from reduced impact logging with those expected from conventional logging under identical local site conditions. • The purpose of the software is to help users learn about reduced-impact logging and its potential financial advantages as compared to conventional logging. • The focus of efforts to introduce							Dykstra, D. 2003

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	RILSIM is on users in tropical countries where logging impacts are widely considered to be incompatible with sustainable forest management.							
General	• Minimizing the negative environmental impacts of logging and other silvicultural treatments is the primary conservation goal in tropical forests managed for timber production. • While it is always environmentally beneficial to minimize unnecessary damage, more intensive silviculture should not be discouraged in tropical forests in which regeneration and growth of commercially valuable timber species requires such treatments. • Failing to regenerate commercial species may render forests more susceptible to conversion to other, more lucrative land uses.							Fredericksen, T.S. & Putz, F.E. 2003
General	• Two hundred and sixty-six studies and articles on RIL and/or CL, conducted in closed broad-leaved tropical forests, were reviewed and classified. • These publications dated back to 1950. Following compilation and analysis, the data extracted were summarized in order to give an indication of some general trends. • It should be noted, however, that the data found in the various reports are not adjusted to account for inflation.		• From a summary 130 observations (n=37 for RIL and n=93 for CL). • The median[2] volume harvested was 8 m^3/ha lower, with RIL at 37 m^3/ha and CL at 45 m^3/ha. • In the majority of the RIL studies the logging intensity was <60 m^3/ha, while for CL there was a significant portion >60 m^3/ha. • 101 observations (45 RIL and 56 CL) showed no significant difference in the number of trees harvested per hectare between the two forms of logging. • The median number of trees harvested was 8 trees/ha for each cutting cycle.	• 21 observations indicated that utilization rates are better with RIL; however, many more studies are needed.	• From 75 observations RIL had 41 percent less residual stand damage, when compared to 49 percent for CL systems. • Other studies which measured stand damage in a different manner, found that median rates of damage for RIL and CL were 124 and 131 trees per hectare, respectively. • In 15 observations the damage to trees per trees felled was 56 percent less in RIL operations when compared to CL operations. • The area covered by skid trails in	• In 33 observations the adoption of RIL resulted in the volume of lost timber being 60 percent lower than in CL operations.	• In 10 observations the median cost of RIL was US$ 0.28/m^3 higher than that of CL. In another two observations the planning costs were reported as costs per hectare. • The range of US$ 5.06 to US$ 50.00/m^3 indicates serious shortcomings in the statistics on planning at this time. • In a total of 10 observations, the median felling cost of RIL was US$ 0.56/ m^3 higher than that of CL. • This represents a cost that is 48 percent higher. In a review of 11 articles no	Killman, W., Bull, G. Q., Schwab, O. & Pulkki, R.E. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					RIL operations is almost 50 percent less than in CL. • From eight observations of road damage, the trend was as expected with a much lower level of damage (41 percent) when using RIL techniques. • In 25 observations with RIL the canopy opening was 36 percent smaller.		appreciable difference in skidding costs between the two forms of logging was found.	
General	• Harvesting trees is a tool for accomplishing many management objectives, and operations can be conducted to protect environmental quality and reduce visual impacts. • Key requirements for environmentally sound harvesting will include good planning, reputable contractors, skilled workers, and professional foresters who understand the concepts and application of sound forest practices.							Long, A.J. 2001
General	• This paper reviews the evidence regarding the viability and desirability of sustainable forest management in the tropics. • Empirical studies suggest that although sustainable timber management sometimes provides reasonable rates of return, conventional timber harvesting is generally more profitable. • This implies that without additional incentives, one cannot expect companies to adopt sustainable management. • In many cases, sustainable timber management performs better in terms of carbon storage and biodiversity conservation than conventional logging approaches, as well as producing more timber.							Pearce, D., Putz; F.E. & Vanclay, J.K. 2003

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	• If new carbon markets emerge, it may also provide a sufficient incentive for sustainable forest management in certain circumstances.							
General	• Despite abundant evidence that both the environmental damage and the financial costs of logging can be reduced substantially by training workers, pre-planning skid trails, practicing directional felling, and carrying out a variety of other well-known forestry practices, destructive logging is still common in the tropics. • The main reasons for this are: 1. RIL is too expensive. 2. There's nothing wrong with current logging practices. 3. Lack of governmental incentives to change logging practices. 4. The forest will be converted anyway. 5. Available equipment is unsuitable for RIL. 6. Lack of training and guidance by RIL experts. 7. Lack of focused pressure for better logging from environmental groups. ▪ Well-managed forests can provide income as well as many of the forest resources and ecosystem services that society increasingly demands, but what is required is nothing less than a cultural change from timber mining to forest management.							Putz, F., Dykstra D.P. & Heinrich, R. 2000
General	• This paper focuses on the potential for using carbon trading to stimulate adoption of reduced impact logging (RIL)-based sustainable forest management. • While the incremental carbon benefits of improving harvesting alone may be rather limited, significant carbon benefits could result if carbon payments could support sustainable forest management in a favourable policy and institutional environment.							Smith, J. & Applegate, G.B. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
General	• The planning and construction of forest harvesting roads is a major and expensive operation that is critical to the orderly flow of logs. • Codes of practice have aimed at setting basic standards to reduce the adverse effects of forest road alignment whilst still meeting operational and other needs. • Such new standards are often opposed by the timber industry as being impractical and uneconomic. • Experience in code development in the Asia-Pacific region indicates that proper road construction, sound environmental management, beneficial social outcomes and operational economics need not necessarily conflict. • It may be necessary to collate, publish and disseminate road construction and management information. • Training for roading supervisors, forest supervisors, forest officers and operators.							Wells, C.H. 2002
General: - Ghana - Cameroon - Indonesia, East Kalimantan - Malaysia, Sarawak	• Greater efficiency in forest and processing operations could greatly enhance the sustainability of the tropical timber industry • Sawn timber yields varied from 36 to 57% depending on country and lumber market • Need to modernize equipment • Need to raise the skill of the workers by practical training and education • Need to establish quality control in mills • Need for better utilization of the mill residues			• Of the total tree on average 4.6% in stump, 5.2% in buttress, 53.5% extracted log, 10.4% stem off cuts, 26.3% in crown with diameter >20 cm • Of stem between crown and stump 77.4% extracted as log				Noack, D. 1995
General: Ghana, Brazil, Venezuela, Indonesia, Malaysia	• Report on sawmill recoveries • Low yields generally the result of lack of skilled labour and management, poor maintenance and saw sharpening, obsolete equipment							Loehnertz *et al.* 1996
Ghana				• Harvesting >3.5 m^2/ha of basal area will exceed the forest's ability to regenerate				Agyeman *et al.* 1995a

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Ghana	• Bura Forest Reserve		• Logging intensity 2.3 trees/ha	• Gap opening per felled tree ranged from 350 to 1800 m^2	• Telling 2.6 trees/ha resulted in 13% logging disturbance • Canopy openings accounted for 50% of the disturbance, skid trails 38% and haul roads 12%			Ayeman *et al.* 1995b
Ghana	• This study evaluated options to make RIL profitable (based on an average concession of 10,000 ha		• Cutting cycle of 40 years • 1/3 of the trees >50cm dbh are allocated for harvest		• RIL: 20% of residual stand damaged • CL: 40% of residual stand damaged • RIL: stocking levels of most valuable timber species improved by 30-50%		• There is a lack of economic incentives for the concessionaire to introduce RIL • An area dependant subsidy of US$ 92.5/ha or a price increase by 147% would be necessary to make RIL financially viable. • Target subsidies fit well into the current institutional setup.	Bach, C. F. 1999
Ghana	• Selection system (dates from 1956) • Detailed location mapping of all commercial trees >68 cm dbh, improvement thinning of immature trees, vine cutting		• Cutting cycle 25 years • 2.5-5.0 trees/ha removed • 26 out of 190 trees that grow to timber size are economically valuable					Baidoe, J. 1970
Ghana	• There is no good evidence that plant biodiversity would suffer as a consequence of logging, providing that careful logging measures are adopted		• Ground-based logging systems for selective logging on a 40 year cycle are used					Hawthorne, W. 1997
Ghana	• The study focussed on the harvesting efficiency and the environmental and social impact of timber harvesting in the area. • For the harvesting efficiency time and production studies were undertaken along with an appraisal of the equipment and personnel. • For the environmental impacts an assessment was made of skid trails and the damage to the residual stand as well as the extent of the canopy openings		• Mean volume extracted per cycle: felling = 13.04; skidding = 10.02.		• 86 trees < 50 dbh were totally destroyed whilst 48 were partially damaged. • n the > 50 cm dbh size class 5 trees were partially damaged.			Odoom, F. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	resulting. • Forest-fringe communities were assessed to determine the sociological impacts of the forest operations.							
Ghana	• The majority of existing market and fiscal incentives (demand side incentives) encourage and promote extraction of high-value species • Control (supply) measures, including management plans, yield allocation, etc., attempt to conserve high-value species and promote extraction of a wider range of lesser used species • Demand side incentives are ineffective, and even deleterious, without attention to supply side issues • Industry will need to accept a far greater responsibility for the resource if current predictions of the extinction rate of key economic species are to be avoided							Sargent *et al*. 1994
Ghana	• Nearly 93% of all forest land in West Africa (Benin, Ghana, Guinea, Guinea Bissau, Côte d'Ivoire, Liberia, Sierra Leone and Togo) has sustained some timber harvesting • As long as harvesting mimics the natural disturbance regimes, the tropical forests of Ghana can be sustained while being harvested • Growth 3-6 m^3/ha/a • Logging methods should be revised to reduce the amount of understorey disturbance • Harvesting secondary species is often encouraged, however, this could lead to great disturbance at each entry		• Minimum felling limit is 70 cm dbh • Cutting cycle has just recently been increased from 25 to 40 years					Wagner, M. & Cobbinah, J. 1993
Guyana	• Comparison of RIL and CL		• 8.2 m^3/ha (2.4 trees per hectare)	• RIL: no merchantable trees were missed	• RIL: 30% reduction of skid trail length possible • Felling trees with vines attached caused significant damage	• CL: 3% waste wood	• RIL: production increased by 7% • RIL: production costs per m^3 reduced significantly	Armstrong, S. & Inglis, C.J. 2000

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Guyana	• Ekuk Compartment, Mabura Hill		• Logging intensity 57 m^3/ha (ecological reserve plot 1988) • Ekuk compartment logging intensity 37 m^3/ha (1990) • Low intensity logging of 20-25 m^3/ha on sandy soils appears to have fairly little impact on the hydrological and nutrient cycle at the catchment level		• Uncontrolled skidding is a major cause of damage to the ecosystem • 12.6% of area with gap openings in logged area vs. 3% in natural area • Average logging gap size three times the size of a natural opening			ter Steege *et al.* 1996
Guyana	• This study was carried out in the Upper Demerara district of Guyana		• RIL was studied with harvesting intensities of 4, 8 and 16 trees/ha respectively • With CL an average of 8.7 trees/ha was harvested (basal area 2.2 m^2; volume 27.8m^3/ha). The variability was high (0 to 25 trees/ha harvested) • With a cutting cycle of 25 years and neglecting mortality a next harvest at 8 trees/ha intensity may be possible. But for the following cutting cycle all trees will have to be recruited from the 20 to 40cm dbh size class, which will take much longer than 25 years. With the same assumptions, stand table projection with a harvesting intensity of 8 trees/ha will result in 27 trees/ha in the 40cm and above size class after 25 years, which suggests that this exploitation level may be sustainable.	• 85% of the residual stand will probably survive at a harvesting intensity of 8 trees/ha with CL, this rate will be reduced to 77% at a harvesting intensity of 16 trees/ha. • With RIL, 89% of the residuals will probably survive at 8 trees/ha and 78% at 16 trees/ha • In the CL operation the average recovered volume per tree amounted to 2.9 m^3 whereas a volume of 3.1 m^3 was recovered on average in the RIL operation	• Ground disturbance in felling gaps occurred significantly more often in CL (6.7% of total area) than in RIL (1.1% of total area). • CL severely damaged a basal area of 1.5 m^2/ha (an estimated 5.1% of the original stand) with no significant relation to logging intensity. RIL seriously damaged a basal area of 0.5 m^2/ha (2.1% of the initial stand) after a light harvest, and a basal area of 1.8 m^2/ha (7.6% of the initial stand) was damaged with a logging intensity of 16 trees/ha • In this study RIL resulted in a reduction in damage to the residual stand by 6% at an extraction level of 8 trees/ha and by 3% at an		• In CL, felling reached a productivity of 10 m^3/h per crew while in RIL productivity only reached a level of 5.8 m^3/h (reduction in felling performance 37% while the operative machine time was increased by 66%) • For skidding the volume delivered at the landing per operative machine hour increased from 11.8 m^3/h to 14.4 m^3/h due to implementation of RIL • CL: costs for pre-harvest planning: US$ 5.06/ m^3 • RIL: costs for pre-harvest planning: US$ 15.52/ m^3 • CL: Costs of harvest preparation US$ 14.87/ha • RIL: Costs of harvest preparation US$ 17.24/ha • RIL increases the up-front costs by US$ 12.83/ha (NPV = $14.69/ha) • CL: Cost of felling, skidding and	van der Hout, P. 1999

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					extraction level of 16 trees/ha • RIL resulted in a reduction of the skid trail coverage from 13% to 8% of the total area at a logging intensity of 8 trees/ha and from 21% to 8.5% at an intensity of 16 trees/ha • Felling and skidding damage taken together, this meant a reduction of irreversible residual damage from 15% to 11% (at 8 trees/ha) and from 22% to 21% (at 16 trees/ha) respectively		landing operations US$ 5.24$/$m^3$ • RIL: Costs of felling, skidding and landing operations US$ 5.58 $/$m^3$ • CL: overhead costs US$ 10.17/m^3 • RIL: overhead costs US$ 9.40/m^3 • RIL: the change in the aggregate logging costs (per m^3) is small (increase of 5%) when the logging intensity is reduced from 16 to 8 trees/ha (from 50 to 25 m^3/ha). The costs rise more strongly, when the intensity is further reduced to 4 trees/ha and even more when subsequently being reduced to 2 trees/ha • RIL is cost competitive with CL. The direct cost per cubic metre may have been higher at the moment but will likely decrease in the future • In the long term several benefits are associated with RIL. Attempts to place a financial value on this are neither realistic nor even desirable for that very reason	
Guyana	• In this case CL featured felling in groups while trees selected for harvesting were scattered in the RIL operation • RIL resulted in a very modest		• CL: harvesting intensity 8 and 16 trees/ha (0-78 m^3/ha) • RIL: harvesting intensity 4, 8 and 16	• Gross volume recovery increased from 2.9 to 3.1m^3 over bark by implementing RIL	• RIL: felling damage was reduced by 16% at a logging intensity of 8		• CL: logging costs US$ 28.29/m^3 • RIL: logging costs US$ 28.23/m^3	van der Hout, P. 2000

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	reduction in residual stand damage and canopy loss. Only the reduction of the skidding trail coverage is in agreement with the results of other studies.		trees/ha; 8 trees/ha corresponds to 25 m^3/ha		trees/ha, whereas it was augmented by 9% at a logging intensity of 16 trees/ha • CL: the average canopy opening per felled tree decreased by 23% when the harvesting intensity was increased from 8 to 16 trees/ha • Liana cutting and directional felling as carried out in this study did not reduce the amount of canopy lost. • RIL reduced the area traversed by the skidder by about 2/3, while skidder movements in felling gaps were reduced by about ¾, both depending on the logging intensity.			
Guyana, Northwest	• Original 227 trees/ha (dbh >20 cm) • CELOS system has partly guided the logging operations at BCL		• Minimum felling dbh is 50-60 cm for the plywood mills • Logging intensity 5 trees/ha or 15 m^3/ha	• Of original stand 183 trees/ha were not felled or damaged	• For every 6 trees logged a further 21 were either pushed or pulled over, or were snapped (1 bent, 17 pushed over, 4 crown snapped, 4 severe crown damage)			Inglis *et al*. 1997
Guyana	• The work on which this paper is based was carried out within the BCL concession and developed from studies of merchantable wood left in the forest and the resulting impact on operational and financial efficiency. • BCL operates a 1.67 million ha concession in Northwest Guyana. • Some very important changes that are required relate to behavioural		• Stocking of commercial species is poor, with harvesting volumes averaging 8.2 m^3/ha. • At an average volume of 3.4 m^3 per tree, this equates to a harvesting intensity of 2.4 trees/ha.					Armstrong, S. & Inglis, C. 2001

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	rather than technical issues. • Involving people in planning change increases the likelihood of success as fears are overcome. • Impractical recommendations and poor communication threaten the change process. • Effective management is the key to improving harvesting operations. • Retaining people with the range of skills needed to implement, manage and supervise improved harvesting practices requires incentives. • New concepts should be suited to local conditions, developed and tested in collaboration with operators and management. • Changes that have been tested and which build on current resources, and skills are more likely to be adopted than new systems.							
Guyana and Cameroon	• Two projects concerning the impact of reduced impact logging on the vegetation in Guyana and Cameroon are compared.		• Exploitation level was the most important damage factor as compared with logging method in both studies.		• In Guyana if felling intensity exceeds 8 trees/ha, the accumulated gap area is less in a conventional operation than in the experimental RIL operation. RIL however produces smaller mean gap sizes. • With an intensity of 8 trees/ha, canopy loss is the same with either method, but, an intensity of 16 trees/ha, canopy loss was higher with RIL. • Skidding damage in canopy gaps is negligible with RIL and extensive with conventional logging.			van der Hout, P. & van Leersum, G.J.R. 1998

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					• In Cameroon large scale climber cutting did not decrease gap size or the level of damage to individual trees. • In Guyana liana cutting did not have any effect on canopy opening. • In Guyana skidding damage was reduced by applying RIL, regardless of logging intensity. • While directional felling and winching are important tool in RIL in Guyana, their application in Cameroon is constrained by the size of the trees.			
Indonesia	• Indonesian Selective Cutting System and Planting System		• Minimum felling limit is 50 cm on a 35-year cutting cycle (specified by law) • Concession rights are 20 years			• Inefficient logging practices have resulted in relative high logging waste of 35-40% partly due to low skill of workers		Brotoisworo, E. 1991
Indonesia	• Tropical lowland forest in Sumatra • Tropical high forest in steep terrain in South Kalimantan		• Average 5 trees/ha (15.8 m^3[sob]/ha) extracted in block studied • Other blocks averaged 18 and 21 m^3(sob)/ha • 155 m^3/ha of total 198 m^3/ha extracted (78% of total volume)		• Average road density was 15-20 m/ha with average skid trail density of 33 m/ha			Buenaflor, V. & Heinrich, R. 1990
Indonesia	• Evaluating the Indonesian Selective Cutting and Planting System				• This system is often considered to cause forest degradation.			Elias 1999
Indonesia	• Project developers believe this project will generate savings of 56,400 tons of carbon over its projected 40-year term				• RIL is expected to reduce the damage to the residual stand by 50%		• A carbon investment would provide training and pay for various RIL activities.	FAO 1998

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Indonesia	• Rainfall 250-350 cm/a and periods of rain for 30-60 days can stop operations completely • Good utilization of all species and log grades (quality) is the cornerstone of intelligent forest resource development and long-term management		• In traditional operations forest stands with gross volumes up to 150 m^3/ha had logging intensities of 20 m^3/ha • Increased to 60-75 m^3/ha through better utilization of felled trees and increased use of lesser used species • A typical stand would consist of 77 m^3/ha of all species with dbh >50 cm • a seasonal logger would extract 36 m^3/ha • a contractor operating on a license would extract 45 m^3/ha • an all-weather logging operation would extract 65 m^3/ha (good infrastructure gives the ability to improve utilization and also a need for better utilization to cover fixed costs)					Schoening, J. 1978
Indonesia	• Both large and small sawmill yield is 45% and waste is 55% (sawdust 10%, slabs 25%, log trim 17%, other 3%) • In 1981 plywood mill yield was 40% and waste 60% • A more recent study showed plywood mill yield at 45% due to technological improvements				• Average road density of 15-20 m/ha is acceptable	• Study 1 wood waste was 12% and 22% stem wood in cut-over, 11% and 17% left at collection sites • Study 2 12% and 18% was in felling and bucking areas, 2.9% and 2.5% in log yard • Broken and defective log volume was 15.5% when calculated on a clear bole basis, and 17.5% when based on		Silitonga, T. 1987

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
						minimum 30 cm diameter • Study 3 found waste wood based on a clear bole basis to be 25.1% in Kalimantan and 21.9% in Sumatra • Study 4 average waste wood was 19 m^3/ha (minimum 1.0 m length and 10 cm diameter inside bark) • Waste wood in tropical rain forest is 24-26% of the extracted volume • If going down to a 30 cm diameter waste wood is 32-35% of the extracted volume • For mangrove forests waste wood is 9% and for teak forests 11%		
Indonesia (Central Kalimantan)	• The average stocking density is 583 stems/ha with a basal area of 34.4 m^2/ha		• 4 scenarios were evaluated: Primary forest, manual extraction, CL (10 trees/ha removed) and RIL (following the FAO model code for forest harvesting practice) • The optimum disturbance regime for seedlings establishment and regeneration will be associated with small gaps (<650 m^2) created by logging and extraction of < 2 trees /gap	• 6 months after logging dipterocarp seedlings were already growing rapidly in disturbed areas	• With CL, 38% of the canopy were completely removed, and 52% of the ground was covered by logging debris or skid trails • Poor growth and survival of naturally regenerating dipterocarps in logged forest could be the result of the removal of host- or site-specific mycorrhizal fungi • The lowest			Van Gardingen, P-R., Clearwater, M.J., Nifinluri, T., Effendi, R. Rusmantoro, W. Noor, M., Mason, A., Ingleby, K. & Munro, R.C. 1998

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					intensity of damage was observed when timber was manually removed • The highest intensity of damage was observed in plots logged by CL (soil disturbed on 30% of the area)			
Indonesia (East Kalimantan)	• The study area was covered by primary and secondary lowland mixed dipterocarp forests		• RIL techniques were applied with two diameter limits (50 and 60cm dbh respectively) • The net annual increment increased from 0.7 m^3/(ha*a) [CL] to 1.3 m^3/(ha*a) [RIL]		Logging damage to the residual stand can be reduced significantly from 40-50% to 20-30% if several recommended improvements to CL methods are implemented.		• The comparison of production costs shows no significant difference in cost between CL and RIL methods	FAO 1997b
Indonesia (East Kalimantan)	• The study was designed to compare CL and RIL under the Indonesian Selective Cutting and Planting system. • The objective of the study is to test the applicability of the *FAO model code of forest harvesting practice (1996)*		• The cutting cycle is 35 years • The harvesting intensity is 3-4 trees/ha		• Opened area caused by felling in CL units is 11.1% and in RIL units it is 7.65%. • Opened area caused by skidding in CL units is 8.73% and in RIL units it is 5.21%. • RIL can reduce the opened-up area by up to 35% when compared to CL • As compared to CL, RIL can lessen damage up to 50% without a significant decrease in productivity		• CL: total cost of harvesting is US$ 2.94/m^3 • RIL: total costs of harvesting is US$ 2.97/m^3 (excluding topographic maps and planning costs) • Assuming a profit ratio of 30% the value of timber damages caused by CL is twice as high as the value of timber damages caused by RIL (US$ 2.94/ha : US$ 1.29 /ha)	FAO 1998
Indonesia (East Kalimantan)	• Data were collected from the STREK project in East Kalimantan		• Three options were analysed (CL, RIL with felling limit 50cm and 60cm respectively)				• · CL: total costs US$ 4.03/m^3 (productivity 35.65 m^3/h) • RIL >60cm dbh: total costs 3.14 US$/$m^3$	Karsenty, A. 1998

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
							(productivity 46.53 m^3/h) • RIL >50cm dbh: total costs 2.95 US$/$m^3$ (productivity 48.42 m^3/h) • The additional costs for RIL should not exceed US$ 20 to 25 per hectare • The cost-benefit analysis shows that $50 to $74 can be saved per hectare with RIL	
Indonesia (East Kalimantan)			• Stand inventories indicated that 15-20 trees of commercial species could be harvested per hectare (estimated volume of 70-90 m^3/ha). • Harvesting was limited to 12 trees/ha with a volume of 75 m^3/ha. • It is expected that the second harvest in the RIL plots could be undertaken within shorter time frame compared to CL operations	• RIL: canopy opened on 18.7% (winching <30m) or 20.4% (winching <15m) • CL: canopy opened on 26% of the total area • The percentage of healthy trees in the residual stand could be increased from 35 to 47% by RIL • The exploitation factor in the RIL plots was greater (85%) than in the CL plots (81%) • The utilisation of timber above the first branch could be increased (often about 4-6m of utilisable timber were left) • At the given harvesting intensity the timber production could be increased by 2 m^3/ha through higher utilisation standards	• CL: undamaged residual stand 22 m^3/ha (dbh 20-40cm); 76 m^3/ha (dbh > 40cm) • RIL: undamaged residual stand 25 m^3/ha (dbh 20-40cm); 100 m^3/ha (dbh >40 cm)		• CL: total production costs 2.74 Us$/$m^3$ • RIL: total production costs 3.51 Us$/$m^3$ • RIL: costs increased by US$ 1/m^3 compared to CL • RIL: under the conditions of this case study a direct financial benefit of US$ 50 per hectare could have been generated, if the company had been allowed to harvest the "additional timber" gained by improved utilisation under its given AAC • There are also long term benefits of higher quality of the residual stand, reduced need for rehabilitation and the possibility of shortening the cutting cycle.	Ruslim, Y., Hinrichs, A. Sulistioadi, B. & Limbang Ganacea, PT. 2000
Indonesia (East Kalimantan)			• Three options were analysed (CL, RIL with felling limit 50cm and	• Only 53.7% of the volume felled were extracted from the	• On average logging affected 34.4% of the area			Sist, P. & Bertault, J.G. 1998

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
			60cm respectively • Timber volume extraction must be limited to 80m^3/ha to achieve the positive effects of RIL	forest	(felling 16.4%, skidding 23.6%) • The main cause of mortality was uprooting during skidding and felling (76.5% and 10.1% respectively) • In this study logging damage was reduced from 48.8% in CL to 30.5% in RIL (felling limit 60cm dbh) • The different logging intensities with RIL did not have a significant impact on the level of logging damage			
Indonesia (East Kalimantan)	• Impacts of CL and RIL on forest ecosystems were compared		• Logging intensity ranged from 1 to 17 trees/ha (9-247 m^3/ha) and averaged 9 trees/ha (86.9 m^3/ha). • With high harvest intensities, a sufficient harvesting volume will not be reached within the cutting cycle of 35 years.	• Leaving only few potential crop trees will result in a seriously depleted residual stand	• With RIL logging damage to the residual stand could be reduced by 50% compared to CL • Above a felling intensity of 8 trees/ha the effectiveness of RIL in limiting damages to the residual stand was significantly reduced, mainly due to the increasing felling damage			Sist, P., Nolan, T., Bertault, J.-G. & Dykstra, D. 1998
Indonesia (East Kalimantan)	• This study was carried out in Indonesia (east Kalimantan) as part of the STREK project • Silvicultural treatments and RIL techniques are evaluated • MAI 0.75 to 4.9 m^3/(ha*year)		• CL: minimum harvesting diameter 60cm dbh • RIL: minimum harvesting diameters of 50cm and 60cm dbh respectively		• 26% of residual stand were damaged during harvesting, resulting in 51% of the total mortality two years after harvesting.			STREK, CIRAD-Forêt & FORDA. 1999
Indonesia (Eastern Kalimantan)	• The average commercial volume found in primary forests in this		• 10 harvestable trees were found per	• On the study site, the volume extracted was	• In the study area, 5.4% of the area		• The average skidding costs were	Ahrenholz, T. 1991

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	region is 101.90 m^3/ha for trees >20cm dbh. • Two harvesting systems were evaluated: the TPI system (Indonesian Selection System) and the HTI system (clear felling and artificial regeneration)		hectare (79.40 m^3/ha) • In plantation forests, 200m^3/ha of commercial timber could be produced on a 12 year rotation. • The following cutting cycles were proposed: saw logs 20-30 years, pulpwood 8-20 years, fuel wood 5 years	equal to the volume damaged or left behind (76.3 m^3/ha)	was affected by roads (primary roads 1.6%, secondary roads with water bound surface 0.5%, temporary secondary roads 3.2%) • 20.7% of the area were affected by skidding • Between 25 and 48% of the skid trails were traversed 4 to 8 times		US$ 2.2 to 2.5 per cubic metre	
Indonesia (Eastern Kalimantan)	• In primary forest, the overall annual mortality rate was 1.5% in number of stems (9 stems /ha*year; 0.57 m^2/ha* year)		• RIL: _80% of the basal area remaining · Intermediate: between 70 and 80% of basal area remaining • CL: _70% of basal area remaining	• The mortality after logging over a period of 2 years was 2.5%/year	• 26% of the remaining stand was damaged after logging (representing 51% of the trees that died during the next 2 years.)	• The drastic reduction of damages obtained with RIL did not result in a significant reduction of the subsequent mortality.		Nguyen-The, N., Favrichon, V., Sist, P., Houde, L., Bertault, J.G. & Fauvet, N. 1998
Indonesia (Eastern Kalimantan)	• Site A: The initial basal area was 33.19 m^2/ha • Site B: the initial basal area was determined as 103.63 m^2/ha		• Cutting cycle 35 years • Site B: harvesting intensity 39.1 m^2/ha	• Minimum residual density of potential crop trees of 25 trees/ha • Site A: The residual basal area was 23.1 m^2/ha • Site B: 44% of the initial basal area remained undamaged	• The area affected by skidding ranged from 11.1% to 13.4% • Site A: a residual basal area of 8.58 m^2/ha was damaged • Site B: 19% of the residual stand were damaged during harvesting			Ruslim, Y. 1992
Indonesia (Eastern Kalimantan)	• This study refers to the Indonesian Selection and Planting System (TPTI) • Winching of logs to the skid trail was not possible due to the large volumes harvested per stem.		• Cutting cycle 35 years	• 20 trees of merchantable size (dbh 50cm) per hectare must be retained	• On average 13.5% of the area were affected by skidding (on 8.7% of the area the topsoil was exposed) • Felling and skidding damage amounted to 30% of the initial basal area • Between 20 and 40% of the			Ruslim, Y. 1994

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					potential crop trees were damaged during harvesting operations			
Indonesia (Eastern Kalimantan)	• Silvicultural treatment can result in growth rates of 10 to 15 m^3/ha		• A 35 year cutting cycle and a harvesting intensity of 35 to 105 m^3/ha appear to be sustainable					Weidelt, H.J. 1989
Indonesia (South Kalimantan)			• The average volume of marketable tree species with a diameter >50cm is 120 m^3/ha • A harvesting intensity of 40m^3/ha is possible with a 35 year cutting cycle					Kuusipalo, J., Kangas, J. & Vesa, L. 1997
Indonesia (Southern Kalimantan)					• CL: 10.6% of the study area were affected by skid trails and log landings			Supriyatno, N. 1993
Indonesia, East Kalimantan	• Lowland dipterocarp • (Lempake)		• 11 trees/ha • (stumps 80-150 cm diameter)		• 41% residual stand damage			Abdulhadi *et al.* 1981
Indonesia, East Kalimantan	• Study comparing conventional logging to RIL • Original stand density 530 +/-63.3 stems/ha; BA 31.4 +/- 3.2 m^2/ha		• Logging intensity ranged from 5-15 stems/ha or 43-174 m^3/ha or 9.8-30 m^2/ha	• Felling mainly injured trees, especially crown damage to trees 30-50 cm dbh • Skidding mainly cause mortality, especially uprooting trees 10-20 cm dbh • RIL reduced damage or death to trees from 48.4% to 30.5% (extra 95 trees/ha >10 cm dbh remained undamaged) • In Borneo damage often exceeds 50%, which is more than in Africa or South America				Berthault, J. & Sist, P. 1997
Indonesia, East Kalimantan	• Dipterocarp forests • Indonesian Selection Cutting and Planting System (TPTI) • Mortality of trees in natural stands varies between 0.9- 2.4%/year, average 1.1%/year		• Cutting cycle is 35 years and the minimum felling dbh is 50 cm • Logging intensities at Narkata Rimba were	• Residual stand damage increases as slope increases (at Narkata Rimba 9.4, 21.1 and 35.4% residual tree damage	• 75% of injuries caused by skidding and 25% by felling • Higher residual stand damage			Elias 1996

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	• At Kiani Lestari the average dbh growth on trees with dbh >10 cm was 0.8-0.95 cm/a one and two years after logging, and 0.47-0.69 cm/a 4, 9, 13 and 17 years after harvesting • dbh growth in virgin forest is 0.51-0.74 cm/a • In plots at Narkata Rimba dbh growth of trees >10 cm dbh was 0.55-1.25 cm/a after logging, but reduced to 0.41-1.04 cm/a after a few years • At both areas average growth rate of commercial trees ranged from 0.90-2.97 m^3/ha/a		2, 6 and 17 trees/ha on slope classes 0-15, 16-25 and >25% • Logging intensities at Kiani Lestari were 8, 9 and 8 trees/ha on slope classes 0-15, 16-25 and >25%	on 0-15, 16-25 and >25% slope, while at Kiani Lestari 38.6, 46.2 and 46.8% residual stand damage on 0-15, 16-25 and >25% slope)	results in higher mortality			
Indonesia, East Kalimantan	• Average standing volume (dbh >50 cm) was 115 m^3/ha (68 m^3/ha dipterocarps; 24 m^3/ha non-dipterocarps; 23 m^3/ha non-commercial)		• Estimated exportable volume 48.5 m^3/ha • Forestry Service in Indonesia accepts 30% waste, thus net extractable volume is 34 m^3/ha • Too optimistic to assume that trees of saw log size will mature in 35 years after logging and that they will constitute the second crop in the following cutting cycle		• 42 m/ha of road to log an area and day-lighting (road right of way clearing) can extend to 50 m from the centre-line of the road on both sides			Hamzah, Z. 1978
Indonesia, East Kalimantan			• Logging intensity 25 trees/ha		• 30% of ground surface covered with tractor paths			Kartawinata, K. 1978
Indonesia, East Kalimantan	• Tropical forest		• Model showed an optimum felling intensity of 71.9 m^3/ha on a 35-year cutting cycle					Mendoza, G. & Setyarso, A. 1986
Indonesia, East Kalimantan	• Sawmill recovery rate was 50% and residue 35% by volume for logs received at the mills • Plywood conversion efficiency was 42-65%, with the average being 55%		• Logging intensity was 5.2-6.9 trees/ha or 42-67 m^3/ha at four logging sites totalling 130 ha	• Logs produced accounted for 63.2% of the felled trees, with residues being 36.8% (stump 5.3%, buttress 3.8%, defective logs 6.0%, branches 21.7%)				Muladi, S. 1996
Indonesia, East Kalimantan	• Mechanized equipment is used in logging and results in considerable damage to the remaining stand		• Logging intensity 25 trees/ha in 4 ha study area • (14 in 14-29.9 cm dbh class; 6 in 30-49.9 cm	• 41 (commercial species) trees/ha left after logging of which 13 trees/ha were dipterocarps	• 50.1% of residual trees had no damage (958 residual trees or 240 trees/ha left			Tinal, U. & Palenewen, J. 1978

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
			dbh class; 19 in 50-69.9 cm dbh class; 60 in >70 cm dbh class)		with dbh >14 cm) • 13.7% were overgrown with climbers • 1.7% had bark damage • 5.2% had crown damage • 0.7 had bark and crown damage • 28.6% of the trees were fallen or broken off			
Indonesia, South Kalimantan	• Study of regeneration capacity of logged over rainforest • In practice currently applied management and harvesting systems do not fulfil the criteria of sustainable forest management • Increasing gap size had a negative effect on height growth of dipterocarps • Larger gap sizes favoured pioneer species		• Recommended maximum gap size is 500 m^2 • In the Indonesian Selective Logging System 10-15 trees/ha can normally be harvested from natural forests					Tuomela *et al*. 1996
Indonesia, West Kalimantan	• Lowland rainforest		• Harvest removed 43% of pre-cut basal area or 62% of pre-cut dipterocarp basal area (average 5.1 m^2/ha)	• Residual dipterocarp (<50 cm dbh) suffered high mortality after logging, possibly limiting future wood supply • 76% of crown cover had moderate to heavy disturbance (45% heavy) • 8 years after logging total basal area was still only half of that in adjacent unlogged areas	• 18.4% of forest floor was disrupted by roads, tractor tracks and skid trails			Cannon *et al*. 1994
Indonesia	• Four case studies were conducted in similar dipterocarp-dominated lowland and hilly forests in East Kalimantan, Indonesia. • The studies were undertaken in Berau; Kutai Induk (near Kutai National Park); PT Sumalindo Lestari Jaya IV concession and the Centre for International Forest Research (CIFOR) Bulungan Research Forest, Malinau District. • The analysis compared the costs of the components measured in	• The selected RIL studies had the felling compartments outlined in the harvesting plans, which were based on accurate topographic maps of between 1:2 000-5 000			• RIL produced a reduction (almost 50 percent) in the damage caused to the residual stand.		• The results from the cost analyses are inconsistent. • The observed inconsistencies and differences do not allow for comprehensive and meaningful comparisons.	Applegate, G.B. 2002

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	the four studies.	scale, with contour intervals of between 5 and 10 m. • The harvesting plans identified planned skid trails and landings and individual tree locations. • Most CL activities on the sites used for the case studies did not have adequate maps for implementing harvesting activities. • There was no planning of skid trails, and directional felling techniques were not employed.						
Indonesia	• Widespread adoption of reduced impact logging (RIL), particularly in tropical forests, will probably remain an elusive goal wherever the forestry policy environment is overly prescriptive, dictating how to achieve sustainable forest management (SFM). • Instead, the focus should be on forest management outcomes that allow site-specific adaptations as well as sufficient regulatory oversight. • Forestry policy development in Indonesia from 1967 to 1999 illustrates the policy problem as well as opportunities to advance RIL. • This paper argues that the basic problem has not been lack of							Bennet, C. P.A. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	enforcement and implementation but the nature of the policy framework itself. • Prevalent and often counter-productive, prescriptive regulations should be reoriented towards outcome-based policies to promote RIL as well as other aspects of SFM.							
Indonesia	• Most forest concessionaires follow the Indonesian Selective Cutting and Planting System (TPTI) and carry out 100% inventories and most of the regulatory requirements. However, combined with an almost total absence of effective field monitoring and enforcement of existing regulations, TPTI is ineffective. • RIL research results in Southeast Asia indicate clear benefits from a productivity point of view and well as environmental benefits. However the financial benefits are not clear and in light if the uncertainties facing the industry in Indonesia, financial benefits must be clearly articulated. • The focus should now be on the implementation of RIL in Indonesia. • Forest companies and forest managers must educate themselves on RIL. Forest operations must be examined and adjustments made where necessary. Gaps in the knowledge and skill levels need to be identified and filled by thorough training. • Governments and funding agencies need to place greater emphasis on the development and delivery of training and extension programs for the forest industry.							Klassen, A.W. 2002
Indonesia	• Sustainable management of logged over forests requires an understanding of the potential yield from the forest and likely financial performance of the management system. • The growth and yield model		• The systems evaluated included one defined by a maximum of 8 harvested stems per ha and others based on maximum volume extracted of either 50	• Average yields from the TPTI system decreased from over 80 m^3/ha for the first simulated cycle to between 35-40 m^3/ha for the third and fourth harvests.			• The TPTI system is not economically viable after the second harvest leaving the only financially viable alternative of land conservation after	Van Gardingen, P.R., McLeish, M.J., Phillips, P.D., Fadilah, D., Tyrie, G. & Yasman, I. (in press)

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	SYMFOR was linked to a financial model derived for a forest concession managed under the Indonesian selective logging and replanting system (TPTI). • This combined approach was used to predict the likely timber yield for contrasting management regimes and then to calculate estimates of the financial performance described as the internal rate of return (IRR) and net present value (NPV) of the forest estate using both the TPTI system and reduced impact logging (RIL).		or 60 m^3/ha. Cutting cycle lengths evaluated ranged from 25 to 45 years.	• Systems based on RIL with a cutting cycle of 35 years with yield regulated to 50 m^3/ha or 45 years with a regulated yield of 60 m^3/ha were the best alternatives to the TPTI system.			clear felling of the remaining forest. • RIL systems were unable to consistently achieve an IRR of 16% unless there were also decreases in waste.	
Indonesia	• PT Inhutani II, a state owned logging company, collaborated with CIFOR in an ITTO funded project to test the RIL approach in its operations. • The main components of the include the development of appropriate logging guidelines and staff training.				• The area of skid trail per volume of timber extracted was twice as high in the conventionally logged blocks as in the RIL blocks (18.6 m^2/ m^3 vs. 8.6 m^2. m^3). • Damage to the stand and canopy increased with felling in the RIL blocks but not in the conventionally logged blocks. • Under high felling intensity (> 9 trees/ha), the proportions of damaged and dead trees in RIL were similar to those recorded in conventionally logged sites.			Machfudh, Sist, P., Kartawinata K. & Efransjah 2001
Indonesia (East Kalimantan)	• PT. Sumalindo Lestari Jaya is an integrated wood-based industry company headquartered in Jakarta, Indonesia. It is operating in the natural forests in East Kalimantan. • This project addressed road construction activities in the swamps of East Kalimantan, and conducted analysis of the logistics of all harvesting options and							Aulerich, D.E. & Sirait, J. R. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	activities. • The objective was to conduct cost-effective harvesting operations while reducing impacts on the environment. • After the initial evaluation of the ongoing operations, cable logging (primarily skylines) seemed to provide the most promising alternative for improving production, decreasing costs and reducing environmental impacts. The primary reasons for this conclusion were the steepness of the terrain, the high rate of soil erosion and the heavy rainfall, which could shut down tractor operations. • Workshops were organized to introduce top management and middle management to the alternatives to the basic ground-based systems being applied. • Meetings were also held with the regulatory agencies and operations people were then identified for training programs.							
Indonesia (East Kalimantan)	• Detailed damage assessments were carried out in five 1-ha plots within two 100-ha compartments, one of which was harvested using RIL and the other by conventional logging.		• Volume felled in all plots was 65 m^3/ha (11-12 trees /ha)		• Opening up caused by skidding decreased by 66% with RIL, while overall opening up decreased by 29%. • Stand damage caused by skidding decreased by 56% with RIL, while overall stand damage decreased by 28%.	• Logging waste was reduced by 20% under RIL		Hinrichs, A. & Ruslim, Y. 2001
Indonesia (East Kalimantan)	• In 1998, the management of P.T. Limbang Ganeca/East Kalimantan and the Sustainable Forest Management Project (SFMP-gtz) launched a RIL pilot project. • The private company was testing and implementing RIL under the			• The net exploitation factor in the RIL plots was higher (85 percent) than that in the CL plots (81 percent). • Efforts have been	• Stand openings following RIL were 29 percent lower than after CL. • In particular, opening up by tractors was	• Logging waste was reduced by 20 percent, although the CL operators were also instructed to reduce waste.	• RIL reduces skidding productivity by 15 percent, volume skidded is therefore reduced to 25.5 ha/mth.	Hinrichs, A., Ulbricht, R., Sulistioadi, B., Ruslim, Y., Muchlis, I. & Hui Lang, D. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	several conditions: RIL should not lead to major additional investments (re-engineering of harvesting machinery and change in methods are not required); RIL should neither reduce productivity nor increase operational costs; RIL should reduce logging waste and RIL should be in line with government regulations and certification requirements. • In 1999, a comparative study was conducted in five 1-hectare plots of two compartments. • The effects of conventional logging (CL) vs. RIL were evaluated, with regard to damage, efficiency, productivity and costs. • Implementation started in 2000 on a 2 350 ha annual cutting block with ongoing monitoring/evaluation by the company, SFMP-gtz and a joint implementation team from the Ministry of Forestry the company and SFMP-gtz.			made to increase timber usage efficiently by cutting the buttresses and placing the undercut properly	reduced drastically (by 65 percent). • The damage caused by tractors usually delays natural regeneration. • The large reduction indicates considerable environmental benefits and demonstrates that forest concessions adopting RIL can pass forest certification more easily. • The residual stand damage due to felling was not particularly different between the two treatments (dbh of trees measured was 20 cm up). • However, damage to the residual stand caused by skidding in CL was far greater. RIL caused 26 percent less overall damage to the residual stand. • In particular, RIL reduced residual stand damage from skidding by 55 percent as compared to CL		• Operational variable machinery costs are estimated to be reduced by between 5 to 15 percent. • The variable tractor costs (especially maintenance and fuel costs) could be reduced by 5 to 15 percent, although additional tractor costs accrue due to the use of higher quality cables in RIL. • Harvesting costs (including planning and operational cost up to roadside/log landings) were approximately US$1.00/ m^3 higher (at an exchange rate of US$1.00 = Rp 6 000). • Additional overheads for human resource development block inspection, team coordination and planning technologies still need to be considered. • Increased operational costs were covered directly by the financial gains due to higher timber utilization (increased net exploitation factor of about 4 percent).	
Indonesia (East Kalimantan)	• P.T. Inhutani I is an Indonesian state forest enterprise managing forest concessions located in several regencies in East Kalimantan and covering a total	• Successful implement-tation of RIL is based on improved			• The results indicate that environmental damage is much lower under RIL		• The results indicate that log production costs are much lower under RIL than CL.	Natadiwirya, M. & Martikainen, M. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	forest area of 1.1 million ha. • Three logging methods were studied at an operational scale, covering 237 trips extracting 1 500 m^3 of timber from three compartments. • Compartment A was logged using a bulldozer and RIL techniques. • Compartment B used RIL techniques and a combination of a bulldozer and a wheeled skidder. • Compartment C was logged using conventional bulldozer techniques.	planning of harvest operations. • Reliable tree and topographic data for the compartments to be harvested are required.			than CL. • The skid trail area opened in CL areas was 1.7 times that of skid trails in the RIL compartment. • Cross-slope trails and cutting depths were also greater in the conventional plots, increasing soil disturbance and machine time.		• The total cost of bulldozer skidding in a well-planned compartment applying RIL was only 67 percent of the cost of CL, mainly because of lower skid trail construction costs and avoidance of delays, both resulting from better planning. • For a standardised compartment (100 ha with 3000 m^3 timber extracted) under CL, the total costs were Rp154 million, and an estimated 48 days were required to log the compartment. • A bulldozer using RIL techniques completed the same work in 32 days at a total cost of Rp 103 million. • The combination of wheeled skidder and bulldozer completed the work in 30 days at a total of Rp 94 million. • The additional cost of improved planning required to execute RIL is estimated at Rp 4 million per 100 ha compartment.	
Indonesia (East Kalimantan)	• The effects of logging damage on forest dynamics processes were assessed in a lowland dipterocarp forest of East Kalimantan, Indonesia. • From 1990 to 1991, twelve 4 ha plots (200 m x 200 m) each divided into four 1 ha subplots were set up and all trees with dbh		• Felling intensity varied from 1 to 17 stems ha-1 (50-250 m^3 ha-1).	• Recruitment remained constant at 8 trees ha-1 per year in primary forest and varied from 14 – 32 trees ha-1 per year in logged-over stand in proportion with the amount of damage. In stands	• In primary forest, mean annual mortality remained constant to 1.5% per year throughout the study period while mean annual			Sist, P. & Nguyen-The, N. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	≥ 10 cm measured and identified at least at the generic level. • Logging was carried out from November 1991 to March 1992 in nine plots while three plots served as control. • Remeasurements were carried out just after logging in 1992and then every two years until 1996.			with the lowest remaining basal area, the establishment and growth of dipterocarps was strongly limited by the strong regeneration of pioneer species.	mortality rate was significantly higher in logged-over forest (2.6% per year). • This higher rate resulted from a higher mortality of injured trees (4.9% per year). • Four years after logging, mortality rates in logged-over and primary forest were similar.			
Indonesia (East Kalimantan)	• Reduced-impact logging (RIL) and conventional techniques (CNV) were compared in a mixed dipterocarp hill forest in East Kalimantan in three blocks of about 100 ha each.				• RIL techniques nearly halved the number of trees destroyed (36 vs. 60 trees/ha). • RIL's main benefit was in the reduction of skidding damage (9.5% of the original tree population in RIL vs. 25% in CNV). • Before logging, mean canopy openness in CNV (three plots only) and RIL (9 plots) was similar (3.6 and 3.1%) and not significantly different. • After logging, the mean canopy openness was 19.2% in CNV and 13.3% in RIL. At a larger scale, the area of skid trail per unit timber volume extracted was halved in the RIL compartment (15 m^2 vs. 27 m^2 m-3 for CNV). • However, under			Sist, P., Sheil, D., Kartawinata, K. & Priyardi, H. 2003

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					high felling intensity (>8 trees/ha), both stand damage and canopy disturbance in RIL approached those recorded in CNV under low or moderate felling regime.			
Indonesia (East Kalimantan)	• Because mixed dipterocarp forests exhibit high densities of timber trees, selective logging based on the minimum diameter cutting rule leads to high felling intensities from 10-20 trees/ha and high extracted volumes of 100-150 m^3/ha. • Under such high logging intensities, RIL objectives cannot be achieved, in terms of damage reduction, yield sustainability and biodiversity.		• Using the model STREK six felling cycles were simulated under constant time and constant extracted number of trees and applied several rotation lengths varying from 20 to 100 years with the several intermediary values: • The extracted number of trees was the mean number of felled trees in the three damage groups: G_1 -6 trees/ha, G_2-8 trees/ha and G_3-14 trees/ha. • The extracted volumes were calculated based on the average volume of dipterocarps in each dbh class tabulated in Favrichon and Cheol (1998). • In G_1, G_2 and G_3, the shortest sustainable rotations were respectively 23, 41 and 92 years, and significantly different. • These rotation cycles give mean harvesting volumes of 2.4 m^3/ha/yr, 2.0 m^3/ha/yr and 1.4 m^3/ha/yr respectively in G_1, G_2 and G_3.	• There is a strong impact of logging damage intensity on forest dynamics: the higher the damage the longer the time of forest recovery. • After logging, density of pioneers increases proportionally with the amount of damage; the most damaged stands show the highest density of pioneers. Results suggest that 30 years after logging, pioneers enter a phase of senescence to reach their original density recorded before logging at about 80 to 100 years after logging. • Commercial species face drastic shifts in their density and structure. • Their capability to adapt to altered environmental conditions created by logging and to maintain populations in the ecosystem after logging will depend mainly the original population density, population structure, regeneration dynamics and breeding systems.	• RIL clearly failed to reduce felling damage on the forest stand significantly. • Skidding damage on residual trees decreased from 25 percent of the original stand in CL to 9.5 percent in RIL. • The proportion of trees destroyed during logging is reduced significantly in RIL by 40 to 50 percent in comparison with CL techniques. • In two experiments in Indonesia (Berau and Bulungan), the proportion of trees destroyed and damaged in RIL plots under the high felling intensity (n >8 trees/ha in Berau, n >9 trees/ha in Bulungan) was similar to that recorded in CL; in both techniques, this affected about 50 percent of the original stand.			Sist, P., Bertault J.G. & Picard, N. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Indonesia (Kalimantan)	• In 1995, the Alas Kusuma concession of PT Sari Bumi Kusuma (SBK), collaborated with the USAID- funded Natural Resource Management Project (NRMP) in conducting an operational trial in which some RIL components were implemented. • One of the main objectives of this study was to evaluate differences in productivity and environmental impact by pre-planning harvesting activities and exerting a tighter control over felling and skidding. • The potential for improved harvesting economics, combined with obvious beneficial environmental results, as indicated by the initial SBK trial, prompted Alas Kusuma to attempt to duplicate this operational experiment on a slightly larger scale on its PT Suka Jaya Makmur (SJM) concession in West Kalimantan. • Results indicated that if large-scale adoption of RIL was to succeed, a number of significant improvements and changes still had to be made in the way the company organized its activities and in the technical competence of its staff. • The company carried out informal 'in-house' workshops where results were presented and discussed. • The staff was also able to discuss the problems and challenges which still need to be overcome before full adoption of RIL is achieved.	• The company's existing contour maps were used as a basis for planning a systematic harvest on a 25 ha area. • Skid trails were planned, located and opened prior to the start of felling activities. • Results suggested that there was the potential of increasing productivity and reducing environmental impact through the adoption of improved operational planning and control.						Suparma, N., Harimawan & Hardiansyah, G. 2002
Japan			• Shown that if the natural forest is managed at a stock level of 70-80% of the climax and a low percentage cutting (13-17%) is carried out on a short cycle (8-10 years) the total harvest volume can be increased without	• Found that it is difficult to keep the stand composition intact with selection cutting of more than 30% of the stand (basal area assumed) • When the cutting percentage reaches 65% the stand composition is				Watanabe, S. 1992

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
			losing the productivity and health of the forest	destroyed				
Madagascar			• Logging intensity 10 m^3/ha					Ganzhorn *et al*. 1990
Malaysia			• Increased from 24 m^3/ha(1971-78) to 45 m^3/ha (1979-90)					Abhluwalia & Karnasudirdja 1995
Malaysia	• Virgin dipterocarp			• Climber cutting prior to logging reduced number of trees pulled down by 50% • Climber cutting and poisoning productivity 1 ha/5 hours				Appanah, S. & Putz, F. 1984
Malaysia	• Dipterocarp		• Simulations show that a 35-year cutting cycle may be too low in the selective management system • (dipterocarps >60 cm and non-dipterocarps >45 cm removed)	• Critical in all simulations is the need to maintain pole size material in the residual stand · if not, no residual stand will develop for the third cut				Appanah *et al*. 1990
Malaysia	• Tropical forest. • Rainfall 3084 and 2308 mm/a for the two-year study period				• Surface runoff generated 454, 10070 and 13341 kg/ha of soil loss in the first year after logging from undisturbed soil, skid trail and logging road, respectively. • In the second year soil losses decreased by 80% for skid trails and 77% for logging road • Recommends skid trails and logging roads not be build on slopes >20%			Baharuddin, K. 1995
Malaysia	• Hill dipterocarp forests		• Average 15 trees/ha felled	• 40.5 ha logging area 35% of basal area (BA) undisturbed, 55% of BA destroyed during extraction and 10% of BA actually extracted	• Road making the greatest damaging factor in hill forest exploitation			Burgess, P. 1971

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Malaysia	• Dipterocarp forests			• Average residual damage in contractor operated areas was 27.8% of dipterocarps and 38.5% of non-dipterocarps • Average residual damage in company operated areas was 32.8% of dipterocarps and 34.5% for non-dipterocarps				Canonizdo, J. 1978
Malaysia				• Greatest menace to advance growth is careless extraction rather than felling				Chai, D. & Udarbe, M. 1977
Malaysia	• After a pilot stage of 3 years (1,400 ha) the calculated greenhouse-gas-benefits were sufficiently positive to warrant the concession for implementing RIL on up to 9,000 ha over the coming 3 years.						• RIL: The approximate cost, based on greenhouse gas savings, is around US$ 1.40 per ton of CO_2	FAO 1998
Malaysia			• Average logging intensities • Sabah 120 m^3/ha • Sarawak 90 m^3/ha • Peninsula 52 m^3/ha	• In coupes logged during the late 1980s, tree losses during felling reached 62% under conventional tractor logging techniques, and 80% under overhead cable techniques	• Levels of damage of the forest are correspondingly high			Grieser-Johns, A. 1996
Malaysia	• Humid tropical forests. • Incidence of injury can be reduced by regular inspections and direction of operations by trained and experienced staff, and by post-logging inspection and enumeration. • A minimum felling limit is needed to limit the intensity of the logging operations; this, however, needs to be complemented by improvement thinning			• Loggers disregard the protection of standing stems of desirable species. • Only 15 desirables/ha were recorded as being both of potential commercial log grade and free from injury • Selective logging eliminated 20% of the total number of stems that existed in the virgin forest	• Selective logging snapped the trunks of 5% and injured more than 66% of all stems >10 cm dbh • 40% of medium-sized trees were damaged, thus jeopardizing the yield in the second cut			Hutchison, I. 1987b
Malaysia	• While the need for plantations cannot be denied, particularly in meeting long-term wood supply objectives, sustained yield management of the natural forest is imperative in most tropical							Jabil, M. 1993

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	countries. • The successful practice of tropical rainforest management for sustained yield requires not only technical expertise and appropriate technologies, but also careful planning and implementation							
Malaysia	• Contract fellers have scant regard to felling sequence considerations or to damages to forest growth					• For every 100 m^3 extracted, 80-105 m^3 of logging wastes are left behind considering materials with minimum dimensions of 0.91 m long and 30 cm diameter (9.3% stumps, 31.4% tops and branches, 2.3% end trims, 50% damaged residual trees and abandoned logs)		Malvas, J. 1987a
Malaysia	• RIL must ensure that an adequate number of 20-60 cm dbh trees/ha are retained in a healthy state after logging		• In ground skidding 89 m^3/ha available for harvest	• 23.1 trees/ha marked for retention • With RIL 19.0 trees/ha remaining (4.2 trees/ha >50 cm dbh) • With unsupervised felling 12.2 trees/ha remaining (1.1 trees/ha >50 cm dbh) • Direction felling saves more crop trees than uncontrolled felling (19 vs. 12 trees/ha) • Bucking length instructions imposed in the woods definitely increases log utilization efficiency of wood processing mills	• Optimum feeder road density 12.5 m/ha (800 m spacing). • 70.4 m/ha of skid trails laid out (average width 4.67 m) and covered 3.3% of area. • Minimum area covered by roads, landings and skid trails slightly over 5%			Malvas, J. 1987b
Malaysia	• Three land use options (catchment protection [CP], conventional logging [CL] and reduced impact logging [RIL]) were evaluated for forested catchments in Malaysia . These findings cannot be		• Harvesting intervals were 30-35 years, (cutting limits >50cm dbh for dipterocarp and 45cm dbh for non-dipterocarp species	• Residual stocking minimum is 32 trees/ha of commercial species of good quality from diameter class 30-45			• Net Present Value of CP option: US$ 5,772,685 • Net Present Value of RIL option: US$ 6,240,075	Mohd Shahwahid, H.O., Awang Noor, A.G., Abdul Rahim, N., Zulkifly, Y. &

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	extended to other forest catchments without making adjustments to the numerical results, such as incorporating different rates of sedimentation, rainfall and sediment concentration.		• For both the RIL and the CL option the net timber yield is 49.3 m^3/ha for the first cutting cycle and 31.6 m^3/ha for the second cutting cycle	cm or its equivalent			• Net Present Value of CL option: US$ 5,396,344 • The efficient choice among the two logging methods is the RIL option owing to the higher returns and the lower externality imposed upon the status quo water users • Complementing water uses with logging in forested catchments is efficient where hydro-electric power is produced.	Tazuni, U. 1999
Malaysia	• Prior to logging, forest structure and composition were similar in CL and the RIL areas, with mean basal area ranging from 25-33 m^2/ha		• CL: minimum cutting limit 60 cm dbh • RIL: Harvesting intensity 87-175 m^3/ha • CL: Harvesting intensity 90-173 m^3/ha	• Four years after logging, woody plant regeneration was better (more stems, greater species richness) in RIL than in conventionally logged areas. Churned skid trails in general showed a greater regeneration potential than bladed trails	• CL: 59% of the residual trees <60cm dbh were damaged • RIL: 29% of the residual trees <60cm dbh were damaged • CL: 140 m^2 of soil were disturbed per harvested tree (6.8% of total area) • RIL: 94 m^2 of soil were disturbed per harvested tree (16.6% of total area) • Skid trails with intact topsoil and litter layer were uncommon with CL, but covered about 12% of the skid trails in RIL units • Soil disturbance was positively associated with harvested volumes in CL areas, but not in		• Tay (1999) observed a greater efficiency of skidding in RIL units compared to CL areas. The skidding costs were US$ 1.98/m^3 for RIL techniques and US$ 4.51/m^3 for CL.	Pinard, M.A., Barker, M.G. & Tay, J. 2000

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					RIL areas • The proportion of skid trails with subsoil disturbance was less than half in RIL areas compared CL areas			
Malaysia	• Diverse in tree species and heavily stocked with commercial trees; average basal area 25 to 33 m^2/ha (dbh> 10cm), about 68% commercial species		• CL: modified uniform system with 60 year cutting cycles, target diameter 60cm dbh • RIL: 70 % of the basal area extracted with CL was harvested • The difference in stocking levels and the higher volume increment could reduce the cutting cycle by 50%. (Kleine 1997)		• RIL reduced the soil disturbance substantially compared to CL, both in terms of area damaged (from 13% to 9%) and degree of disturbance • The damage to the residual stand could be reduced from 50% to 28% of the original stems by implementing RIL		• RIL caused additional direct operating costs of US$ 135/ha or US$ 1.27 /m^3 (Tay, 1999) • RIL: US$ 45 /ha was spent on monitoring (less intensive monitoring may be sufficient on operational scale)	Pinard, M.A., Putz, F.E. & Tay, J. 2000
Malaysia	• Lowland dipterocarp forest · wood vines increase damage associated with felling and slow rates of regeneration after selective logging. • Vine cutting should occur sufficiently before felling to allow the vines to die and decay							Putz 1985
Malaysia			• RIL: felling cycle may be reduced		• Forests harvested with RIL may recover faster (canopy openings create favourable conditions for re-generation) • The only method for reducing felling damage that is currently available is to limit the level of cut.		• The long term benefit of RIL will most likely arise in the reduction of the felling cycle	Sist, P. 2000
Malaysia	• Comments based on 1987 visits to several SMS sites • As practised then did not hold much hope of success in respect of sustained commercial volume production, except where		• The SMS by design may yield a second cut of comparable volume to the first; however, it will contain a proportion of less-		• Logging damage and undue selection of logs extracted (in 1987) still appeared			Wyatt-Smith, J. 1988

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	Dryobalanops aromatica (kapur) predominates • Economic cut of the best commercial species equitable to the logger appeared to carry the greatest weight in practice rather than ensuring sustained yield management of the valuable species		desirable commercial species (current standards) • The major problem will be in the volume available in the third and subsequent cuts		excessive • Quite clear that the operations in the concessions visited were not sustainable • In reference to Thang (1987) states that a 30% damage factor (built into growth model) to intermediate-size trees at each cutting is unacceptably high, although unfortunately probably realistic			
Malaysia	• Logged in 1959				• Area damaged by logging roads and compartment boundary 9%, covered by crowns 28%, covered by boles 2% (total 39%)			Wyatt-Smith, J. & Foenander, E. 1962
Malaysia (peninsular)	• The system incorporates directional felling and improved road construction		• Cutting limit 45-50cm dbh · Cutting cycle of 30 years		• RIL: 30% of the total volume were damaged during harvesting · CL: 40% of residual stand assumed to be damaged		• Higher skidding efficiency in RIL operations • RIL: logging costs reduced by 4% (RIL 13.39 US$/$m^3$; CL 13.93 US$/ m^3) • RIL: damage equals 61.92 US$/$m^3$ (discount rate 4%) • CL: damage equals 85.88 US$/ m^3 (discount rate 4%)	Ahmad, S., Brodie, J.D., & Sessions, J. 1999
Malaysia (Sabah region)	• Dipterocarp forest with a high density of commercial logs • The mean carbon storage over a 60-year cycle is -38.39 tonnes per logged hectare with RIL and -94.31 per logged hectare with CL. • Particularly because of the potential opportunity costs associated with RIL, this outcome should not be relied upon for other regions		• At the second cut (60 year cutting cycle) greater yields are expected from RIL areas than from CL areas • With RIL, 59.4 m^3/ha were harvested • With CL, 135.2 m^3/ha were harvested	• Following logging, 50% of the logged material is assumed to be converted to timber products			• Organisational and operational expenditures increase when implementing RIL • Revenue will be foregone through the lower timber volume logged by RIL operations • Comparison with	Tay, J., Healey, J.R. & Price, C. 2000

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
							carbon prices derived in other ways shows that, using the same discounting assumptions, the costs of retaining carbon by RIL is expensive compared with most other carbon prices.	
Malaysia, Peninsula	• Hill dipterocarp forest				• Disturbance to 17.8% of soil area with tractor logging and minimum felling diameter of 60 cm· damage to seedlings in high-lead areas (50-57%) was higher than in tractor-logged (38-48%) areas • Damage to trees >10 cm in high-lead area were 24%, 26% and 38% with 45 cm, 60 cm and 52 cm minimum felling limits • Tractor damage (trees >10 cm dbh) ranged from 8% (45 cm min. dbh) to 21% (60 cm min. dbh)			Borhan *et al.* 1987
Malaysia, Peninsula	• Mean basal area 26.9 m^2/ha • Conventional logging had a minimum felling limit for dipterocarps of 65 cm dbh and 45 cm for non-dipterocarps • Planned logging (RIL) had a minimum felling limit of 90 cm dbh for dipterocarps and 60 cm for non-dipterocarps			• Stocking removed in conventional logging was 40% while in the planned and supervised logging it was 33%	• Conventional logging had 60 m/ha of logging road and 80 m/ha of skid trail and no buffer strips were specified • Planned logging had 70 m/ha of logging road and 30 m/ha of skid trail, and 20 m buffer strips on each side of the			Nik, A. & Harding, D. 1993

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					stream • Conventional logging area had 55% higher water yield than the planned logging area, although the percent of forest removed was only 21% higher • Ground disturbance area (skid trails, logging roads, landings) was limited to 5.1% in the planned area, while in the conventional logging area it was 7.1%			
Malaysia, Peninsula	• In hill and dipterocarp forests a shift to more selective management • Need appropriate felling limits and leaving an adequate number of medium sized trees of marketable species for natural ingrowth into commercial sizes		• Under the Malaysian Selective Management System a logging intensity of 30-40 m^3/ha on a 25-30 year logging cycle is expected					Thang, H. 1986
Malaysia, Peninsula	• Data based on a series of 100 continuous inventory plots (0.4 ha each) and another 100 experimental cutting or silvicultural treatment plots		• With average annual growth rates of trees >30 cm dbh of 0.8-1.0 cm and 2.0-2.5 m^3/ha/a in commercial gross volume, about 75% of the hill forests are capable of producing 40-45 m^3/ha on a 30-year logging cycle • This is about the current average outturn level of virgin hill forest	• To account for harvesting losses such as felling breakage, defects, high stumps and short logs left in the forest, potential net volume extracted is 60% of the gross volume for trees with dbh <60 cm and 70% for trees with dbh >60 cm	• Damage levels by dbh class in SMS were >60 cm=20%, 45-60 cm=30%, 30-45 cm dbh=40%, 15-30 cm=50% • Important to curtail logging damage to the residual stand to not more than 30% of the intermediate-sized trees (30-45 cm dbh)			Thang, H. 1987 (same data presented in FAO 1989b)
Malaysia, Peninsular	• With average growth rates of 2-2.5 m^3/ha/a in commercial volume for trees .30 cm dbh and 0.8-1.0 cm/a of dbh, about three quarters of the hill forest is capable of producing at least 40-45 m^3/ha on a 30-year logging cycle		• Current average logging intensity in hill forests is 40-45 m^3/ha					Mok, S. 1992

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	• Growth and yield studies in Sabah and Sarawak have shown similar results							
Malaysia, Sabah	• Logging residues were all pieces >2 m in length and >45 cm diameter			• On average 9.4% of the actual log production was left as residues in the landings and almost 54% of the residue logs were free of any • By moving from a 60 cm dbh felling limit to 40 cm the allowable harvest volume would increase from 114.5 million m^3 to 169 million m^3 • 1984 sawmill recovery 50% • 1984 plywood mill recovery 44%		• On average logging waste amounted to 18.3% of the actual log production defects • Total utilizable waste based on removed log volume was 27.7%		Bhargava, S. & Kugan, F. 1988
Malaysia, Sabah	• Mixed dipterocarp forests · 20 plots, each 5.76 ha • 310-440 trees/ha (dbh >10 cm), of which 10-20 stems/ha with dbh >60 cm • Basal area 28.3 m^2/ha of which 57% were dipterocarps		• Felling intensities >100 m^3/ha are common · minimum felling limit is 60 cm	• Climber cutting had no impact on felling accuracy	• Skid trail placement at 60 m and planned			Cedergren *et al.* 1996.
Malaysia, Sabah					• Total damage from logging amounts to as high as 30-50% of the total land surface			Chai, D. 1975
Malaysia, Sabah	• Dipterocarp · preferable to manage the regenerating forest than plant dipterocarps in open areas • Undue destruction of regenerating forests should not be allowed, and the Forestry Department should endeavour, as far as possible, to impose rules and regulations in respect to logging damage			• In one study 13.7% of original number of seedlings present before logging were still alive 3 years after logging (19350 seedlings/ac reduced to 2450 seedlings/ac) • Major mortality occurred during logging				Chim, L. & On, W. 1973
Malaysia, Sabah	• 80% or more of the stand >60 cm dbh is generally dipterocarps		• Logging intensity generally 89 m^3/ha, although stands may reach 267 m^3/ha	• Top diameter is 48 cm, but sometimes smaller material is removed • Also found that the higher the felling cut on the tree, the higher	• 33.6% of residuals had little or no damage, 53.5% were fallen or broken off and 12.9% had major crown and/or bark			Fox, J. 1968

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
				the losses to log shattering, splitting and torn bases	damage • Of 42.5 potential dipterocarp residual crop trees/ha in the study area, only 14.3 trees/ha had little or no damage			
Malaysia, Sabah			• Based on silvicultural experience in Sabah, a dipterocarp stand can produce 15-30 trees/ha or 45-90 m^3/ha (>60 cm dbh) of marketable timber species each cutting cycle • Article does not give length of cutting cycle (assuming 30-40 years)					Kleine, M. & Heuveldop, J. 1993
Malaysia, Sabah					• New tractor tracks (D4 and D6 class crawler tractors) cover 25% of areas with mechanical extraction • For manual extraction (kuda-kuda) skid trails cover 4% of area • During rain the extraction stopped, and for heavy storms normally stopped for one or two days due to the tracks being too slippery • Along the most heavily used parts of the tracks, up to 1 m of the upper soil layers were pushed aside			Malmer, A. & Grip, H. 1990
Malaysia, Sabah	• Dipterocarp forest · RIL and proper selection harvesting are essential elements of sustained		• In eastern Sabah the average log weighs 7-9 tons and 80-100	• RIL not only minimized all external environmental costs	• Research plots demonstrated a 50% reduction in			Marsh *et al.* 1996

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	management of tropical forests • After logging the area must be closed from further operations and skid trails rehabilitated		m^3/ha are extracted • RIL logging intensity 103 m^3ha (8.8 trees/ha) • Conventional logging intensity 139 m^3/ha (13.6 trees/ha)	but also assures greatly improved future harvests with little or no need for further silvicultural treatments	all measures of damage with RIL when compared to conventional logging, for an increase of about 10-15% in direct logging costs • Restrictions in wet weather skidding slowed operations considerably in RIL areas and added to cost • In RIL logged areas skid trail area average 3.8% of the area, compared to 12% in adjacent conventionally logged areas			
Malaysia, Sabah	• Average dipterocarp forests in Sabah can produce between 1.25-2.075 m^3/ha/a of millable timber over a 40-year period (50-83 m^3/ha)		• Average logging intensity 69 m^3/ha • 50-83 m^3/ha possible on a 40-year logging cycle	• 40 years after logging (high lead logging) the average dipterocarp volume per hectare is half of that of adjacent unlogged forest	• Between 20-40% soil disturbance with heavy equipment			Meijer, W. 1970
Malaysia, Sabah	• Analysis suggests that 2-3 m^3/ha/a net growth rate after logging is achievable, compared to plantation growth rates of 12-20 m^3/ha/a			• With logging severity 20% and 23% net growth was 0.8 and -1.7 m^3/ha/a 7 years after logging • With logging severity of 36 and 76 % net growth was -2.4 and -16.3 m^3/ha/a 2 years after logging • Mean dbh growth for trees in 35-44.9 dbh class were 0.7, 0.4. 1.0 and 1.6 cm/a for virgin forest, and 4%, 15% and 20% logging severity, respectively	• With logging severity (% of original stems cut, damaged and destroyed per plot) less than 15% net growth rates of 3.4-5.9 m^3/ha/a were found 7 years after logging			Miller, T. 1981
Malaysia, Sabah	• Hilly area • Training required for all levels of the hierarchy, from tree fellers to senior management • In the initial analysis of RIL it was more expensive due to the extra activities required (detailed		• 8-15 trees/ha (80 m^3/ha) normally extracted • 800 ha area studied with logging intensity of 120 m^3/ha with RIL and conventional		• In RIL area 20 m/ha of roads (1.6% of area), 71 m/ha of skid trails (4% of area) and 57 m^2/ha of log landings (0.6% of			Moura- Costa, P. 1997

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	inventories, training, climber cutting, intensive supervision) • After the initial period of training and learning it is expected that RIL operations will run more smoothly and efficiently than conventional operations, and thus savings will accrue through lower bulldozer use, fuel and maintenance costs		logging		area), for a total coverage of 6.2% • In conventional logging area 24 m/ha of road (3.3% of area), 205 m/ha of skid trails (13% of area) and 103 m^2/ha of landings (1.0%), for a total coverage of 17.3 • In RIL area 29% of residual trees damaged • In conventional logging area 56% of residuals damaged			
Malaysia, Sabah					• Soil disturbance by tractor trails bare of regeneration averages 14% of the logging area			Nicholson, D. 1958a
Malaysia, Sabah	• Study showed that even with 45% severe to moderate damage to residuals, there were still 20 trees/ha between 10-60 cm dbh which had received no damage and which could yield a stand as good or better than the one just logged		• Logging intensity 11.6 trees/ha or 116.5 m^3/ha	• 35% of the undamaged trees had good form and 12% had poor form	• 53% of residual trees were damaged (fallen or broken off trees 30%, bark damage 11%. crown damage 4%, minor damage 8%) • Amount of damage to residuals increases with logging intensity			Nicholson, D. 1958b
Malaysia, Sabah	• Dipterocarp forests • A well-regenerated forest depends on a careful logging operation • Only extraction has the potential to reduce the regenerating forest to a mass of useless weeds, by destroying existing seedlings and poles				• General tendency for the intensity of logging to increase with the passage of time and for tractor damage to increase • In 1958 14% of the area was impacted, while in 1965 bared area had increased			Nicholson, D. 1965

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					and figures as high as 40% were estimated • Though some rise is probably inevitable, it is not conceded that tractor damage must rise in proportion to the intensity of logging • The most destructive damage appears to stem from inefficient use of tractor tracks and landings • Should also avoid excessive use of the dozer blade and increase the use of the winch and cable			
Malaysia, Sabah	• Dipterocarp forests • Cost of rehabilitating 7 ha of log landings with mixed indigenous species with a 2x1 m spacing was US$1100/ha		• Logging intensity varies but rarely exceeds 10-12 trees/ha					Nussbaum, R. & Hoe, A. 1996
Malaysia, Sabah	• Refers to same study as Pinard *et al*. 1995		• First cuts in Amazon usually <50 m^3/ha • First cuts in Africa usually <30 m^3/ha	• More and larger trees remained undamaged in RIL, hence future biomass increment and yields of marketable timber are expected to be greater in RIL areas than in the conventional logging areas	• No correlation found in study between volume removed and damage to residuals			Pinard, M. & Putz, F. 1996
Malaysia, Sabah	• RIL results in reduced bulldozer maintenance cost, lower bulldozer skidding time, no need for enrichment planting and logging cycle time can be reduced due to less damage to residuals • Need for good training of all people involved from fellers to technicians and foresters		• Minimum felling limit 60 cm dbh • Logging intensity typically 8-10 trees/ha or 80-100 m^3/ha, although it ranges from 50 to 120 m^3/ha • In the study area the logging intensity was 154 m^3/ha in conventional logging area and 104 m^3/ha in		• In RIL areas skid trail coverage was 3.4%, while in adjacent conventional logging areas it was 12% on average • 38% of trails in RIL areas had soil exposed, while in conventional			Pinard *et al*. 1995

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
			RIL area		logged areas 87% were exposed · RIL resulted in 50% less damage to soil and residual trees • An associated 40-70% of the residual stand is damaged • Vine cutting reduces damage, reduces post felling vine infestations, and increases light to the forest floor before felling and thus smaller trees can adjust • 37% of trees uprooted in conventional logging, while it was 13% in RIL			
Malaysia, Sabah			• Trees >60 cm dbh logged and average logging intensity 94 m^3/ha		• Even in 15-year old logged-over forests of Ulu Segama, the traces of log landings and skid trails are visible as treeless patches and corridors			Pinard *et al.* 1996
Malaysia, Sabah	• Clear felling operations		• Volume extracted at site W4 146 m^3/ha (145 trees/ha) and site W5 129.7 m^3/ha (146 trees/ha) (based on volumes transported to landings)		• Tractor tracks covered 24% of the clear felled area			Sim, B. & Nykvist, N.1991
Malaysia, Sabah	• Increase in fires due to forests becoming more prone to fire after disturbance by logging (debris and opening up of canopy) • Of the 1 million ha burnt in Sabah in 1983, 85% has been logged over • Of the estimated 3.5 million ha of tropical forest burnt in Kalimantan, 77% had been logged-over forest							Woods, P. 1989

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	• In addition to more fires, tree mortality in burned logged-over forest is higher than in unlogged forest (38 to 94% vs. 19-71%)							
Malaysia, Sarawak	• Moist dipterocarp forest • Mean annual dbh increment of all trees >10 cm dbh in control areas was 0.22-0.34 cm/a, in overstorey removed areas 0.37-0.44 cm/a, and liberation thinning areas 0.45-0.56 cm/a (if only reserved trees measured in this case 0.77-0.99 cm/a)		• 1974-1980 selective logging extracted an average 5-15 trees/ha (10-50 m^3/ha) • With improvement thinning could have a polycyclic system with 60-year rotation and 30-year cutting cycle					Hutchinson, I. 1987a
Malaysia, Sarawak	• Predicted timber yields in cut-over hill mixed forest assuming RIL • Quality group 1 contains 179 timber tree species (5% of tree flora) and group 1-3 contains 785 tree species (23% of tree flora) • The practices of the labour force in the forest directly cause much of the damage; practically no formal training for fellers or tractor and skidder operators (experience is passed from one to the other) • Tractor and skidder operators are paid piece rates by most companies, and fellers by all companies; the emphasis is on output and not on the minimization of damage • Safety standards are usually low • These weaknesses are exacerbated by inadequate staffing of the Forest Dept. and the consequent inability to exercise the degree of supervision required of		• Present logging intensity 38 m^3/ha • 40-year cycle untreated with 60 cm minimum dbh felling limit 25.7 m^3/ha (quality group 1) and 32.6 m^3/ha (quality group 1-3) • 40-year cycle untreated with 45 cm minimum dbh felling limit 37.7 m^3/ha (quality group 1) and 47.6 m^3/ha (quality group 1-3) • 40-year cycle treated with 60 cm minimum dbh felling limit 33.2 m^3/ha (quality group 1) and 42.4 m^3/ha (quality group 1-3) • 40-year cycle treated with 45 cm minimum dbh felling limit 63.8 m^3/ha (quality group 1) and 82.4 m^3/ha (quality group 1-3) • if the harvest were limited to trees 60 cm dbh or more and quality group 1, cutting cycles of 45-50 years would be necessary to attain the present harvest level of 38 m^3/ha		• The yields indicated can never be achieved by continuing present practice, which is damaging to the environment and the residual stand			ITTC 1990

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Malaysia, Sarawak	• Hill forests	• Lack of planned skid ways in the forest leads to the creation of numerous tractor paths for seeking logs	• Logging intensity varies from 4-20 trees/ha • Average logging intensity (1974-1978) was 25 m^3/ha, with the standing volume being 94-145 m^3/ha • Planned logging cycle is 25 years, but it is doubted this short of a cycle is appropriate, especially due to the high damage factor					Lee, H. 1982
Malaysia, Sarawak	• Recommends RIL • In mixed dipterocarp hill forests the average tree size is 5-6 m^3/stem and 60-80 cm dbh		• Minimum felling limit is 45 cm dbh • Volume greater than 46 cm dbh (all species) 131.4 m^3/ha • Logging intensity 28.7 m^3/ha					Mattsson-Marn, H. 1982
Malaysia, Sarawak	• Mixed dipterocarp hill forest • Study comparing 122 ha area logged with RIL and 122 ha area logged conventionally • Total skidding cost (including RIL associated planning, layout and supervision costs) was M$4.56/$m^3$ compared to M$5.94 for the current system		• RIL logging intensity 55 m^3/ha · Conventional logging intensity 53 m^3/ha	• Found that 11 m^3/ha (20% of total volume of sound timber felled) of logs had been felled and bucked, could not be found by the skidder in current operations versus 5.5 m^3/ha in the planned block	• With RIL overall damage to residuals reduced by 50%, skidding efficiency increased 36% and there was no cost increase with directional felling			Mattsson-Marn, H. & Jonkers, W. 1981
Malaysia, Sarawak	• Total cost of wood delivered to mill (including all planning, layout, logging, roads, road transport, overhead costs) was M$31.71 in unplanned area and M$29.88/$m^3$ in planned area				• More defects, splitting and other felling damage in the unplanned area • 174 m/ha of skid trail in unplanned area vs. 136 m/ha in planned area (22% less) • 7% of area covered by trails in unplanned area vs. 5% in planned area (4 m wide trails)			Mattsson-Marn *et al.* 1981
Malaysia, West	• RIL may add M$51-70/ha, whereas post logging silviculture treatments (including planting of roads and landings) may cost M$200/ha							Andel, S. 1978

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Malaysia, West	• Dipterocarp forest		• Logging intensity 18 trees/ha (24 m^2 basal area/ha), with minimum felling diameters of 45 and 60 cm depending on species		• The mechanized extraction of 3.3% of trees >30 cm dbh destroyed 50.9% of the trees (3.3% extracted, 4.8% destroyed during road building, 3.6 % destroyed when building landings, 39.2% destroyed during felling operation and log dragging • Of the 49.1% remaining standing trees 6.0% were damaged			Johns, A. 1988
Malaysia	• Rimbaka Forestry Operations has recently started introducing RIL to its operations. • The Rimbaka Timber Harvester is an innovative machine developed by the company to reduce the density of skid trails during log extraction.				• Average length of skid trails in forest logged with the Rimaka Timber Harvester was less than 40 m/ha and the total area damaged was approximately 15%; well below the threshold set within the Malaysian Criteria and Indicators.			Sarre, A. (2001)
Malaysia (Sabah)	• Reduced-impact logging (RIL) is one means of reducing the carbon emissions held responsible for global warming. • Comparable effects of RIL and conventional logging were studied in Sabah, Malaysia.			• RIL reduced the area logged within a tract by 44% and resulted in a 22% reduction in timber yield per logged hectare when compared to conventional logging.	• RIL resulted in less damage than conventional logging.		• RIL resulted in an 18% increase in costs per m^3 logged as compared to conventional logging. • Per m^3 of timber logged RIL was beneficial without discounting, but had a net cost at a 2% discount rate and higher. • The overall cost of RIL's carbon retention varied in both discount rate and level of	Healey, J.R., Price, C.& Tay, J. 2000

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
							analysis, from negative price to more than US$ 50 per mega gram at a 10% discount rate. • RIL appears most cost-effective on a per m^3 logged basis at low discount rates. • However, at commonly applied discount rates (4% and above) RIL's carbon price exceeds most published estimates for carbon prices.	
Malaysia (Sabah)	• In a recently logged forest, the seed sources and seedling establishment between conventional logging (CL) and reduced impact logging (RIL) and between two soil disturbance classes.			• More pioneer seedlings established on RIL than on CL plots, but survival of planted seedlings was lower under RIL, due to denser canopy cover.				Howlett, B.E. & Davidson, D.W. (in press)
Malaysia (Sabah)	• From 1992 through 1998, PG&E National Energy Group (NEG) conducted a series of projects to test and demonstrate the application of reduced impact logging as a method for producing verifiable and quantifiable carbon sequestration. • NEG verified that RIL had been successfully implemented by the inspection reports of an Environmental Audit Committee. • It is estimated that over the 40 years following harvest, the first RIL project will sequester 485,000 tons of carbon.							PG&E National Energy Group 2002
Malaysia (Sabah)	• The study was conducted as part of a project located in the Sabah Foundation forest concession area in Sabah, Malaysia. • The pilot phase of the project comprised 1 400 ha and lasted three years from 1992 to 1995. • In 1996, the project area was expanded by another 1 000 ha.	• Prior to harvest, total stem densities for trees greater than 1 cm DBH in the CL and RIL units were 4 382 and 3 798	• The mean volume of timber extracted in the RIL and CL units of 106 and 136 m^3/ha, respectively, was within the extraction intensity of 40-160 m^3/ha reported in other parts of the	• Of the 176 ha allocated to the CL units for logging, almost all of the area was logged. • In RIL units, only 129 ha (56 percent) of the 230 ha was logged. • The net timber volume	• In extracting 9 to 13 trees of above 40 cm DBH, the overall damage inflicted on the residual forests averaged 60 percent and 30 percent in the CL		• The net contribution of RIL from the first harvest (t_0) was less than half of CL. • The lower NPV_{RIL} was due to high extraction costs,	Tay, J., Healey, J. & Price, C. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	• The objective of the financial assessment was to compare RIL with CL in terms of costs and benefits. • The assumption is that observed post-logging differences between RIL and CL can be attributed to the different logging methods rather than to variations between the sites. • The data were generated directly in the study area through the establishment of a network of growth and yield plots. Eight forest management units totalling 406 ha were divided into four pairs. In each pair, one unit was subjected to RIL and the other to CL during 1993 and 1994. • The analysis covered two cutting cycles at year 0 (t0) when the first harvest was undertaken in the primary forest, and at year 60 (t60) when the second harvest will be made.	trees/ha. • The original stand structure did not differ significantly for the six DBH classes (1-5, 5-10, 10-20, 20-40, 40-60, >60 cm DBH) except for trees with 1-5 cm DBH.	study area.	foregone in RIL amounted to approximately 35 m^3/ha. • The benefit of directional felling was most evident for trees in the 5-40 cm DBH range where the remaining stem density was higher in the RIL units compared with the CL units.	and RIL units, respectively. • The total area of skid trails, log landings and roads in the RIL units was only 40 percent of that in the CL units. • They represented approximately 7 and 17 percent of the total area logged in the RIL (129 ha) and CL units (175 ha), respectively. • All three categories of openings (skid trails, log landings and roads) in the RIL units were smaller than in the CL units, but only skid trails showed a significant difference in area between the treatments. • RIL units had a smaller area of skid trails occupying 4 percent of the total area logged compared with 12 percent in the CL units.		and a lower yield. • RIL costs 18 percent more than CL. • The bulk of the additional cost comprised extraction costs at RM18/m^3 or 12 percent of CL. • Harvest yield at t0... RIL=106 m^3/ha CL=136 m^3/ha. • Harvest yield at t60... RIL=111 m^3/ha CL=85 m^3/ha • For the second harvest (t60), RIL and CL yielded RM223/ m^3 and RM289/ m^3 resp., without discounting. The reduction in profit due to the adoption of RIL was 23 percent of CL. • For the first harvest, the profits generated from using RIL and CL were RM2 912/ha and RM7 715/ha, respectively. • The 62 percent lower profits for RIL were due to lower harvested volumes. However, if only extraction activities were considered, RIL costs RM344 more than CL (RIL = RM9 573 and CL = RM9 917). • For the second harvest, the NPVRIL and NPVCL without discounting were RM24 701/ha and RM24 554/ha, respectively.	

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Malaysia (Sarawak)	• The WTK Organization was the first company to implement helicopter logging in Sarawak in 1993. • Helicopter logging in usually applied to areas inaccessible to more conventional extraction methods.		• Average volume per turn 5 - 7.5 m^3; average turn time 3-4 minutes; average volume per effective working day 600-700 m^3.		• Helicopter logging caused considerably less damage to soil and residual forest than tractor logging. • Number of trees damaged or removed per tree extracted was 1.4-3.1 for helicopter logging compared to 5.5 for tractor logging. • Open space created by canopy openings and skid trails as a percentage of logging area was between 4-11 for helicopter logging vs. 15.9 for tractor logging.		• Helicopter logging is more expensive per unit volume than conventional logging.	Chua Kee Hui, D. 1996
Malaysia (Sarawak)	• Helicopter harvesting was introduced to Sarawak in April 1993 by WTK Organisation (a local timber company). • This system of extraction is now used by many timber operators in Sarawak because of its high production performance and its ability to extract logs from otherwise inaccessible areas with minimal damage to the surrounding forest.			• No. trees felled and extracted = 1.4 - 3.5 per ha compared with 8.7 per ha for tractor logging.	• No of trees damaged or removed per tree extracted = 1.45 - 3.13 compared with 5.49 for tractor logging. • Area covered in canopy gaps = 4% - 11% compared with 15.91% for tractor logging.	• The volume of remnant and rejected logs left in the field is quite high (as compared to tractor logging) due to the selection of only good merchantable logs for lifting. • Based on a per tree extracted basis, about 1.8 to 2.3 m^3 of utilized timber are left behind in an area harvested by helicopters compared to 0.08 m^3 for tractor based harvesting.	• High capital and operating costs of the helicopter. • Higher contract rates for felling crews. • Helicopter harvesting cots twice as much as conventional tractor harvesting.	Chua Kee Hui, D. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Malaysia (Sarawak)	• The FOMISS - Sampling Pilot Area (FSPA) a is located in the Upper Baram of northeast Sarawak, covering 169 000 ha. • Comparative financial and economic analyses of CL and RIL with tractors for the FSPA were carried out. • The financial costs and benefits of CL were analysed over two different time frames: (a) after one-year of harvesting and (b) after a 40-year rotation period in a logged-over forest. • The project established 13 RIL trial blocks in the FSPA. • Additional data were obtained from RIL trials in the Model Forest Management Area (MFMA) in Sibu.	• Fifty percent of the FSPA comprises primary forests with an average commercial volume of 303 m^3/ha. • The average stocking of logged-over forests averages 170 m^3/ha.					• The costs of harvesting and royalties per m^3 are approximately 23% higher under RIL relative to CL for the 1-year period. • If the introductory costs for training and damage assessment are excluded, the difference is reduced to 14%. • The profit was estimated at RM29/ m^3 and RM45/ m^3 under CL and RIL, respectively. • If the introductory costs are excluded the profit increases to RM52/ m^3. • The profit is reduced to RM20/ m^3 if the concessionaire does not obtain a certification premium. • The profit per ha of the net production area totals RM1176 for CL and RM883 for RIL. • CL was slightly more profitable and exceeds the NPV of RIL by a factor of 1.3 after 40 years. • The BCR for RIL exceeds that of CL by a factor of 1.1. • This means that RIL is more robust with regard to cost increases. • In terms of the financial cash flow, the first harvest was more profitable under CL than	Dagang, A.A., Richter, F., Hahn-Schilling, B. & Manggil, P. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
							under RIL, whereas the financial benefits of the second harvest were higher under RIL. • The economic analysis showed that the RIL system provided a higher level of overall benefits as opposed to CL after the 40 year period.	
Malaysia (Sarawak)	• In June 1996, the Sarawak Timber Association (STA) collaborated with the SFD, to start a tree-felling training program to supplement existing training programs provided by the SFD and other government agencies. • STA has been involved in the training of tree fellers for about 36 months and has so far trained 508 persons. • The training concentrated mainly on occupational health and safety and directional felling. • STA faced the following problems: (a) lack of availability of qualified trainers and an appropriate curriculum (b) difficulties in access to the training sites (c) cultural (esp. language) barriers and (d) the high cost of training.							Kho, P.C.S. & Chan, B.S.T. 2002
Malaysia (Sarawak)	• Data on cost, productivity, and damage to the residual stand as well as data on soil compaction were obtained from RIL and CL trial blocks in the FOMISS-Sampling Pilot Area (FSPA). • In addition, timber wastes due to poor utilisation and lost logs are estimated based on data collected in the FSPA. • Figures on forest growth are predicted with the Dipterocarp Forest Growth Simulation Model (DIPSIM).		• Overall harvesting volume of the first harvest under CL averaged 44.5 m³/ha and in the RIL blocks the harvesting volume averaged 27.8 m³/ha. • The potential harvesting volume in the second harvesting operation 40 years after the initial harvest would be 23 m³/ha in CL and 83 m³/ha in RIL. • However, the		• The percentage of severely damaged trees was reduced from 54% under CL to 28% under RIL.	• Timber wasted: RIL a UF of 80% was calculated and for the CL a UF of 75% was estimated. • Under CL the volume of timber wasted due to logs left on the log landing or due to second trimmings amounts to 20% of the total extracted volume, whereas	• The economic value of timber revenues averaged RM 351/m³ for CL and RM 387/m³ for RIL (including a 10% certification premium). A total NTFP value of RM 6,798 per block (100 ha) and year was calculated for CL and a value of RM 9,764 for RIL. • The annuity per block with regard to soil erosion	Richter, F. 2001

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
			maximum harvesting intensity under RIL was set at 40 m³/ha/y.			in a planned harvesting operation the log wastage approaches 0%.	benefits was estimated to be RM 1,442 (year 1-10) and RM 9,034 (> year 10) under CL and RM 4,526 (year 1-5) and RM 10,126 (> year 5) under RIL. • In addition the following annual recreational benefits per block were obtained: RM 189.5 for CL and RM 1,895 for RIL. • The annual economic value of biodiversity per block amounts to RM 625 for CL and to RM 898 for RIL. • The profit was estimated at RM 29 and RM 45 per m³ under the CL system and the RIL system respectively. • However, considering the extracted volume, 4,005 m³/100 ha NPA under CL vs. 1,942 m³/100 ha NPA under RIL, the CL system is more profitable. The total profit per 100 ha NPA amounts to RM 117,566 under CL and to RM 88,318 under the RIL system.	

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Malaysia (Sarawak); Guyana; Indonesia	• In this paper, four cases are discussed in which the author was involved directly: the RIL methods developed in Sarawak in the 1970s, in Suriname in the 1980s and in Guyana and Cameroon in the 1990s. • The Sarawak method was tested in a dipterocarp forest on undulating terrain, in a logging concession approximately halfway between the towns of Miri and Bintulu. • About 14 trees/ha were harvested, yielding about 54 m^3/ha. • The Celos Harvesting System developed by Hendrison (1990) was meant for the "Forestry Belt", a 40 to 120 km wide and 400 km long zone in the northern part of the country. • The terrain is flat to undulating. • Some 5-8 trees/ha are harvested, seldom yielding more than 20 m^3/ha. • The spatial distribution of commercial timber trees is usually random. • Several RIL studies have been conducted in Guyana, but only the activity at the Tropenbos site near Mabura Hill is discussed here. • Two RIL studies have been conducted in Cameroon, but only the Tropenbos study is discussed here. • The Tropenbos site is located in the southwest of the country. • In conventional logging, the area under skid trails was only 4.3 percent. • With RIL just a modest reduction to 3.9 percent could be realized. • More important is that after RIL skidding, part of the vegetation had survived on 47 percent of the trail length, compared to 29 percent after conventional logging. • A difference in costs between RIL and conventional logging could not be demonstrated, although the RIL method is probably somewhat less				• In the case of the Sarawak Study: although the method had not been designed to reduce logging damage, the number of trees destroyed by logging had almost been halved. • The Celos method (Suriname) significantly reduced logging damage. • The area under skid trails was reduced by about 50 percent to a mere 5 percent of the total area. • For Guyana, again, RIL reduced the area under skid trails by about 50 percent. • The number of trees damaged by skidding was reduced by the same percentage. • Felling damage was not reduced, however, and may even be more severe than in conventional operations if felling intensity is high. • This is because in conventional logging, trees are more likely to be felled into existing felling gaps, thus creating less damage but larger canopy openings.		• In the case of the Sarawak Study: the planned way of working, logging costs per cubic meter extracted were reduced by 23 percent, which is due partially to lower skidding costs and partially because less timber had been wasted. • For the Suriname study, the results were comparable to those obtained in Sarawak: additional expenditures for surveys, planning and pre-harvesting operations added about 5 percent to the logging costs. • This increase was more than compensated for by reduced skidding costs and improved efficiency. • For Guyana, the costs per cubic meter extracted under RIL were slightly less than under conventional logging. • The difference would have been more substantial if the same felling limits had been applied in both methods.	Jonkers, W.B.J. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	expensive.							
Mexico	• Cable yarding operation in selective cutting. • Initial stand volume 163.1 m^3/ha (113 adult trees/ha) • marked volume 65.3 m^3/ha (45.3 adult trees/ha) • Average piece size 0.78 m^3		• Extracted volume 41.4 m^3/ha (45.3 trees/ha felled)	• 63% of marked and felled trees utilized	• Of residual component 4.6 m^3/ha or 4.7% of the residual component had severe or medium damage			Hernandez-Diaz, J. & Delgado-Pacheco, M. 1996
Mexico			• With a cutting cycle of 15-20 years, 0.5 to 1 tree can be harvested per hectare		• Felling and skidding cause canopy gaps of 200 to 350 m^2 per tree felled		• For 1986 the following production costs were recorded: furniture wood 2,532.41 US\$/m^3, secondary wood 1,823.34 US\$/m^3 • The costs for pre-harvest inventory were estimated at 253.24 US\$/m^3 (1-1.5% of the revenue)	Steger, N.E.1988
Mozambique	• Five companies were studied in detail In order to establish information on the efficiency of commercial forest harvesting in Mozambique.		• Mean volume produced per cycle (Vm) varied between 0.26 m^3 and 1.34 m^3. • Mean distance from one felled tree to the next ranged from 22 to 79 m.			• Recovery rate (RR) ranged between 35% and 63%	• Mean annual investments in machinery with annual production volume indicated capital intensities (IC) between 20.45 and 63.03 US\$/m^3 • Operational costs accounted for most of the unit costs (between 52% and 78%), whereas labour costs did not exceed 16%. • Ownership costs ranged between 9% and 40%, depending on how heavily the companies invested in	Fath, H. 2002

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
							extraction machinery and transport vehicles. • Total effective unit costs ranged between 80.40 and 364.14 US$/$m^3$.	
Nigeria				• Average log conversion rate at the stump was 36.2% with a maximum of 54% recorded		• A large amount of useful wood is left in the forest because of the adherence of the dealers and buyers to specific flitch dimensions		Agom, D. 1994
Nigeria					• Extraction in the concession was heavily mechanized and productive, but caused considerable disturbance to the surrounding areas	• 12.2% waste		Agom, D. & Ongar, D. 1994
Nigeria	• Moist tropical forest • Study of 5 high forest reserves show mean annual increments of about 5.0 m^3/ha/a +/- 1.0 m^3 (of which 2.5 m^3 was exploitable species and 1.2 m^3 was veneer quality species)		• Results suggest the forest can withstand a logging intensity of 35 m^3/ha of log removals on a 25-year felling cycle (50 m^3/ha of bole volume) • Need to set minimum felling limits					Lowe, R. 1992
Nigeria	• Nigerian tropical shelter wood system • Increment in natural forests about 2 m^3/ha/a • On average <20 stems/ha with dbh >50 cm • Total volume in stems >40 cm dbh was 100 m^3/ha and for dbh >60 cm 75 m^3/ha • Growth rate for plantations 15 m^3/ha/a with a total exploitable volume of 300 m^3/ha		• Logging intensity in the 1940-1950s was 20 m^3/ha compared to a total stem volume >200 m^3/ha • With current methods, the total exploitable volume averages 100 m^3/ha of which 30 m^3/ha is actually extracted on a cutting cycle of 50 years					Lowe, R. 1978
Nigeria	• Omo Forest Reserve • Lowland rainforest • Basal area in undisturbed forest 29 m^2/ha; disturbed forest 14.3 m^2/ha; and secondary regrowth 11.7 m^2/ha		• Logging intensity 9 m^3/ha • Manual logging with logs lifted directly onto lorries		• 8% of area bared for manual and lorry method compared to 30% for mechanized operations			Ola-Adams, B. 1987

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					• 17.7% of residual trees damaged • 51 trees were knocked over (mostly in the >30 cm girth classes)			
Papua New Guinea	• Wawoi-Guavi case study showed logging planning and engineering costs were more than offset by skidder productivity increase of 44% • (planning cost 1.08 K/m^3, while skidding costs saving was 1.43 K/m^3)		• Logging intensity about 30 m^3/ha, but can be as low as 15-25 m^3/ha • Estimated that with RIL harvest intensity could be 60 m^3/ha on a 30-year cycle	• Over 40% of residual trees 20-50 cm dbh are damaged by uncontrolled skidding • Wawoi-Guavi case study showed 67% of residuals damage in uncontrolled logging area with 23 m^3/ha removed, while in controlled logging area 22% of residuals damaged with 32 m^3/ha removed	• Over 30% of most logged areas are destroyed by uncontrolled skidding • Skid roads about 100-120 m/ha or 4.0-4.8% of area • Vanimo case study with non-compliance of logging plan had road right-of-way widths of 25 and 18 m, when 14 m was planned; skid roads 5 m wide when planned to be 4 m; 20-30% of area damaged • Wawoi-Guavi case study area had 13.7% of area damaged in uncontrolled logging and 11.0% of area damaged in controlled logging			Buenaflor, V. 1989
Papua New Guinea	• Manus Province • AAC calculations assume 30 year cutting cycle and average 0.75 cm dbh growth per year, along with 10% reduction for breakage and defects • Proper selection logging is not seriously practised by many logging operators			• RIL needs to be implemented to maintain environmental stability in the area and there is a need to retain some of the trees in the 50-60 cm dbh class				Buenaflor, V. 1990
Papua New Guinea	• *Araucaria cunninghamii* dominated tropical rainforest • Initial basal area 42.1 m^2/ha of which 29.4 m^2/ha was *A. cunninghamii* • Dbh increment in the logged area was 0.71 cm/a and 0.36 cm/a, one and two years after logging		• 64 of 67 commercial sized (dbh >40cm) *A. cunninghamii* extracted	• Selective logging was very destructive to all size classes of *A. cunninghamii* • Of the 101 remaining *A. cunninghamii* 60 were destroyed during logging and 4 more	• Destruction of advance growth will increase the logging cycle of *A. cunninghamii* by 100 years due to the slow initial growth			Enright, N. 1978

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	• Corresponding dbh increment in undisturbed site was 0.39 and 0.42 cm/a			died within 14 months after logging (56 *A. cunninghamii* >10 cm dbh remained of initial 168 • The number of sapling was reduced from 66 to 7, and a further 4 died within 18 months • Of the 143 trees of non-commercial species only 9 survived				
Papua New Guinea	• In planned operations skidder production is increased from 8.4 m^3/machine hour to 12.1 m^3/machine hour (+43.7%) • Planning is essential if logging operations are to be applied in an orderly manner and damage to the forest and the environment reduced to a minimum		• Logging is very selective with a minimum felling limit of 50 cm dbh (59 m^3/ha +/- 13.3 m^3/ha), although companies dealing with export markets have a 60 cm dbh minimum felling limit with an average logging intensity of 30 m^3/ha • Companies rarely log areas with less than 20 m^3/ha • Potential yield increase is 50% if all commercial species down to 50 cm dbh harvested (45 m^3/ha) • The MAI at its worst will be 0.6 m^3/ha/a and best 2.5 m^3/ha/a and the logging cycle will be from 30 to 40 years • A felling cycle of 30 years should be adopted for tactical planning and 40 years for strategic planning • Also justified to use a volume increment between 0.8 and 1.7 m^3/ha/a for predicting future volume availability	• Poor logging adds another 10-20 years to the logging cycle due to the loss of advanced growth	• The greater than 30% of area covered by landings, roads and skid trails could be reduced to 15%	• High stumps and bucking to a 40 cm top results in considerable waste, with further losses due to excessive trimming, lost logs and unfelled trees of commercial quality		FAO 1991

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Papua New Guinea	• Tropical high forest • Average portable sawmill recovery 55% (44-56% range)		• Logging intensity 5-8 stems/ha or 30 m^3/ha on average	• 10-35% of the export volume was left at the harbour as not fulfilling export grade rules	• Volume of trees damaged during traditional logging operations and left in the forest was found to be about 15 m^3/ha in size classes from 20-50 cm dbh (17% of total volume) • Number of stems damaged (dbh >20 cm) was 229 of 673 residual trees or 34%	• Studies by FAO have shown that nearly half of the timber volume felled during commercial harvesting operations in tropical forests remains as unutilized residues • After logging 60 m^3/ha of merchantable size standing timber left, plus 30 m^3/ha of uncommercial mature trees		Kilkki, R. 1992
Papua New Guinea	• Clear felling was not as disastrous as many people predicted				• Within a few months of clear felling, bare ground was covered with natural regeneration, but new growth was less diverse • In the clear felled area soil phosphorous was 50% of that in closed forest • Compacted tractor trails and landings, and denuded slopes and hilltops developed in many cases into grassland			Saulei, S. 1984
Papua New Guinea	• The study was carried out in the concessions of Vanimo Forest Products Pty Ltd. (VFP), holder of Timber Permit TP10-8, and Stettin Bay Lumber Company Ltd. (SBLC), holder of Timber Permit TP14-52. • The study documents each phase of the forest harvesting system currently applied by the above-mentioned companies, and		• The time required to fell a single tree was greater on Set-up M38/SBLC (21.48 min) than on Set-up BL14/VFP (17.37 min) although the average stem volume was almost the same, 5.9 m^3 and 5.8 m^3 respectively.		• The forest area occupied by skidtrails amounted to only about 5% due to the hilly to mountainous terrain conditions in Set-up BL14/VFP.	• 90% of the total timber loss at study site BL14/VFP was due to undiscovered decay prior to felling and stems split during felling. • Total timber		Winkler, N. 2001

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	compares planning and implementation of harvesting operations in the field against relevant regulations as published in the *Papua New Guinea Logging Code of Practice*.					losses amounted to about 8.2% at the study site, or 1.57 m^3/ha.		
Paraguay	• This study evaluates the potential for investments in degraded subtropical forests			• When forests are clear-felled, only 10% of the timber volume is used as commercial timber or fuel wood (Bozzano and Weik, 1992)			• Even without consideration of interest rates, depreciation and overhead administrative costs the initial treatment of degraded forests produces a deficit of US$ 137.77/ha	Wippel. B., Grulke, M., Becker, M. & Huss, J. 1997
Philippines					• Increased horsepower utilization is directly related to degree of forest devastation • Regeneration of dipterocarps in a mixed dipterocarp forest (Quezon) is enhanced by the conditions present in a properly logged forest			Blanche, C. 1978
Philippines	• Virgin dipterocarp forest		• Volume removed in two logging settings 205 m^3/ha and 120 m^3/ha		• Supervised logging settings had significantly more uninjured trees in 20-60 cm and +70 cm dbh classes than unsupervised settings • (i.e., 65-72% vs. 26-48% in 20-60 cm class, and 40-47% vs. 23-36% in +70 cm class)		• Sensitivity analysis showed that production costs could increase 30%, yield per hectare decrease by 30% and product price decrease by 20% and a profit could still be made	Bote, P. 1983
Philippines	• Tropical rainforest, Eastern Mindanao • General poor logging performance has resulted in secondary growth that is below the optimum potential		• Growth plots in residual stands show a total volume of 90 m^3/ha just after logging, whose					Reyes, M. 1978

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	of the forest • To have more young trees left uninjured after logging requires the training of fellers in felling techniques and yarding crews in yarding and skidding techniques, all with the objective of minimizing destruction and injury to young trees		predicted volume 30 years after logging is about 260 m^3/ha of which the harvesting volume of trees >60 cm dbh is 160 m^3/ha (growth 2.33 m^3/ha/a) • Growth models show that on a 40-year cycle a silviculturally treated stand could yield 375 m^3/ha compared to 182 m^3/ha in an untreated stand					
Philippines	• Stem distribution charts showing stocking levels by diameter class to ensure successful regeneration of dipterocarp forests using selective logging • There has been a noticeable shift in attitude from predominantly exploitive-oriented to conservation-oriented logging		• Assumes MAI of 3 m^3/ha/a on a 35-year cutting cycle (105 m^3/ha) • Empirical data shows that old growth saw timber cuts vary from 60 to 180 m^3/ha • Based on prescriptions for the new selective logging system the yields may only be 30-90 m^3/ha • When selective logging is done properly it has been shown in three study areas that permissible cuts at the end of the cutting cycle were almost equal if not greater than the average from the old growth	• Field studies done in the 1950s found that 58% or more of the young trees could be saved by the loggers using their ingenuity to avoid hitting marked young trees				Reyes, M. 1983
Philippines	• Shows a commercial forest industry can make a profit and at the same time protect the integrity of the environment and practice sustainable operations • With adequate protection the second forest can return to almost its original form • Control is required of illegal logging, shifting cultivation and the urge to re-log areas close to the mill before the full cutting cycle time is up		• Cutting cycle of 35 years • Field study 33 years after logging shows 123.5 m^3/ha available of all species in the >60 cm dbh class • Growth modelling has projected the third growth volume to be 322 m^3/ha (>20 cm dbh), vs. 200 m^3/ha in second growth and					Tabudar, E. 1984

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
			261 m^3/ha in original stand • However, they have a problem of meeting the Government requirement that the second growth forest should yield a minimum 67 m^3/ha					
Philippines	• Average volume in dipterocarp forest ranges from 100-200 m^3/ha					• For every 100 m^3 removed from the forest, 50 m^3 of logging waste and residues are left		Virtucio, F. & Torres, M. 1978
Philippines					• Studies indicate that a harvest of 50% of the basal area results in damages to 25% of the residual stand			Weidelt, H.J. 1989
Philippines, Eastern Mindanao	• Dipterocarp forest in rough terrain				• Uncontrolled removal of utilizable timber at 10-15 years after initial logging caused excessive destruction to the residual stands • Only 49.9% of the original stand was undamaged			Mauricio, F.P. 1984
Republic of Congo	• Rain forest • Any form of utilization which relies on natural regeneration must be based on a wider range of species		• Logging intensity 1-2 trees/ha (10-15 m^3/ha dbh >= 80 cm) on a 30-35 year cycle • Expected rotation of individual trees is 100 years (dbh 70-80 cm)					Fickinger, H. 1992
Solomon Islands	• As the intensity of logging increases, the decrease in shading allows climber species to become the dominant vegetation • One example required nine maintenance operations annually to control the climbers, at considerable cost				• In the 1960s and early 1970s logging was more selective and soil damage by extraction affected 10-15% of the area and the canopy was broken in places but by no means removed			Neil, P. 1984

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					• In the late 1970s, with the increase in the number of species utilized and acceptance of small logs, logging because increasingly intensive became essentially a clear felling with 70% of the area disturbed or compacted • The result of the very intensive logging was a massive invasion of climbers which choke out the natural regeneration and planted trees			
South America	• Timber species are not uniformly distributed throughout the forest; logging intensity can therefore vary significantly within the same locality		• Logging intensities of 5-6 trees/ha or 30-50 m^3/ha were found in the study area		• 25-40 % of the original tree population were damaged during logging			Sist, P. 2000
South America	• Indicators of environmental impact and financial performance were compared for case studies of tropical forest logging from the Brazilian Amazon, Guyana and Ecuador. • Each case study presents parameters obtained from monitoring initial harvest entries into primary forests for planned, reduced impact logging (RIL) and unplanned, conventional logging (CL). • Differences in cost definitions and data collection protocols complicate the comparative analysis, and suggest that caution is necessary in interpreting results. • Uncertainties concerning the marginal benefits of RIL relative to familiar, profitable conventional practices pose an obstacle to broader adoption. • Moreover, CL firms face few incentives to alter their operation						• RIL can generate competitive or superior profits relative to CL if the financial costs of wood wasted in the harvesting operation are fully accounted for. • Increased operational efficiency is an important benefit of RIL, one that largely determines its cost-effectives relative to conventional practices.	Boltz, F., Holmes, T.P. & Carter, D.R. 2003

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	unless they face dramatic changes in market signals. • Adoption of RIL techniques as part of a long-term forest management regime faces additional challenges related to the opportunity cost of silvicultural prescriptions and timber set-asides to maintain productivity and ecosystem integrity.							
Southeast Asia Southeast Asia	• In Malaysia data 100-0.4 ha continuous inventory sample plots and 100-4 ha experimental and/or silvicultural treatment plots gave average growth rates of trees >30 cm dbh as follows • all species 0.8 cm/a • meranti 1.05 cm/a • medium-heavy marketable species 0.75 cm/a • light non-meranti marketable species 0.8 cm/a • non-marketable species 0.75 cm/a • 2.2 m^3/ha/a gross volume growth for all marketable species • 2.75 m^3/ha/a gross volume growth for all species • Some sceptical of increasing increment of dipterocarp forests above 2-3 m^3/ha/a, and in India the average growth rate is only 0.5 m^3/ha/a after a century or more of management • Mixed dipterocarp forest • Increasing impact of logging probably due to a reduction in quality of supervision and training, increased use of mechanized equipment, careless handling of equipment by unskilled operators, and increasing reliance on horsepower rather than on technical competence • Dipterocarps need a heavy logging and then a long period of closure as can be provided by a bicyclical system. However, it may be necessary to impose limits on the first cut in the interest of those that follow • It is reasonable to use a minimum dbh growth of 1 cm/a for all sizes		• Minimum felling diameter 50 cm for dipterocarps and 45 cm in non-dipterocarps in Malaysia SMS • In Malaysia minimum cutting intensity to be economic estimated to be 35-40 m^3/ha, with a cutting cycle of 35-40 years • Logging intensity in Malaysian Peninsular hill forest could 40-45 m^3/ha on a 30-year cycle (assuming 0.8-1.0 cm dbh growth per year), however, need to limit logging damage to not more than 30% of intermediate-sized trees • Shortening felling cycle and increasing logging intensity in natural tropical forests will lead to a vicious cycle of liquidation • Wide range of logging intensities in the region • In a Philippine case study longer logging cycles had higher MAI (30-year cycle had 1.6-2.8 m^3/ha/a MAI, while 40-year cycle had 2.0-3.5 m^3/ha/a) • even the 40-year cycle suggested may be too short if significant	• Felling damage to intermediated sized trees (dbh >30 cm) assessed to be 30%	• For 1974-1983 forest destruction occurred over an average 21% of the area logged per year • in the 1950s 14% of the area was bared by tractors, while in the 1970s >40% was being bared • Area destroyed by tractors needs to be limited to a maximum of 20-25%	• Wastage due to breakage and poor bucking 6.5-8% of the gross timber volume		FAO 1989b (also in Thang 1987)

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	and the error if any, would be on the safe side; for silviculturally treated stands a minimum value of 1.25 cm/a could be used • Very short pulpwood rotations in conjunction with enrichment with fast-growing species cannot be considered in dipterocarp management since no seeding will occur		seeding does not occur by this time • In the Philippines a 40-year logging cycle is recommended • In Sabah, due to excessive logging and stand damage in the past, a 60-year cycle will be needed to get the stands back into better shape, after which a 40-year cycle could be used • In Sarawak a 40-year cycle is recommended, but believes the 45 cm diameter cutting limit is too low • In West Malaysia, due to problems in inventory and logging, a 60-year cycle is recommended, but it should be possible to go to a 40-year cycle once the forest becomes stable • In Indonesia a 40-year cycle with a minimum yield of 2 m^3/ha/a is possible when silviculturally treated					
Southeast Asia	• Examples of sustainability criteria for dipterocarp forest management		• Minimum felling limit 60 cm		• <15% of harvested area with bare soil exposure • <20% felling damage to residual stem number • <15% extraction damage to residual stem number			Nicholson, D. 1979
Southeast Asia	• Dipterocarp forests • Avoidance of damage should be the primary objective of management • Although MAI of 1.0 cm/a dbh growth and 1.0 m^3/ha/a or higher			• A less severely damaged forest recovers more quickly after logging				Ong *et al.* 1996

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	are achievable with good management, it is wrong to use these numbers when conventional logging is practised							
Southeast Asia	• An additional source of damage which is increasing alarmingly is illegal cutting • In the Philippines strict guidelines are prescribed for selective logging and the use of devices to minimize damage in felling and yarding is required; however, proper supervision is lacking in most cases		• Projected harvest levels in the second cycle cut projected to be from 63.6 m^3/ha (36% less with 40-year cycle) to 83.2 m^3/ha (44.5% less on a 35-year cycle)					Putz, F. 1994
Southeast Asia	• Dipterocarp forests • Volume increment without deducting mortality on an area of primary forest may range from 1-5 m^3/ha/a • Imperative that damage is minimized to both the soil and the residuals		• The absolute minimum logging cycle in dipterocarps is 35-40 years • The minimum felling diameter should be 50 cm, since dipterocarps generally reach fruiting age at dbh 35-40 cm	• If 15 trees/ha are felled 30% of the area would sustain felling damage	• 30% of the area sustains skidder damage • With directional felling techniques about 200 m^2 of area is damaged per tree felled			Serna, C. 1986
Southeast Asia - Peninsular Malaysia - Philippines - East Kalimantan	• Hill dipterocarp • In Malaysia average dbh growth from plots ranges 0.3-0.9 cm/a		• SMS with cutting cycle of 25-30 years and min • Economic cut of 30-40 m^3/ha with initial removals at about 100 m^3/ha • RIL not done so current selective systems are not sustainable on a 35-40 year cycle • PSLS cutting cycle 30-40 years and logging intensity of 70-90 m^3/ha but must be drastically reduced • Richer forests in Mindanao 100-120 m^3/ha but such high yield forests have dwindled quickly	• For success need an effective monitoring system and logging damage must be drastically reduced • Need to leave sufficient numbers of trees 30-45 cm dbh to form trees of next cut, plus sufficient seed trees to obtain new regeneration • In SMS logging damage to residual (dbh >30 cm) estimated to be 30%, not including mortality several years after logging • Need to implement RIL				Weidelt, H. 1996
Southeast Asia, mainly Malaysia, Sarawak	• Mixed dipterocarp forest of southeast Asia • Sustained level of production estimated at 2-3 m^3/ha/a of net industrial volume of desired species >30 cm dbh		• On a cutting cycle of 40 years the logging intensity should be 80 m^3/ha of which 50% can be used • The average net		• In many cases half or more of the trees remaining after logging are damaged, some of them so badly			Appanah, S. & Weinland, G. 1990

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	• Careful harvesting extracts more of the felled trees and leaves a less disturbed forest with greater potential to rehabilitate itself • There is no reason to tolerate harvesting operations that are wasteful and damaging		industrial volume possible to take out after 40 years will be about 40 m^3/ha, which is equivalent to that of the initial harvest • The above assume RIL		that they will die • Entry into the stand to remove additional trees before the full logging cycle is up causes heavy damage to saplings and seedlings • If continued, the re-logged forest often deteriorates into a state of unproductive weeds			
Southeast Asia: Indonesia Malaysia Philippines	• Broadleaved tropical forests		• When extracting lower value smaller and lesser used species a minimum logging intensity of 20-30 m^3/ha is required for the operation to remain economical		• Road densities in moderate and hilly terrain logged by tractors and managed on a sustained yield basis are often from 10-20 m/ha, with 15 m/ha being a good average • 20 % main roads, 20-30% area roads and 50-60% feeder roads			Korsgaard, S. 1985
Sri Lanka	• Wet zone natural forest • These forests have been logged a number of times and the growing stock has reached a very low level in many areas					• Up to 70% of wood being logged from natural forests is wasted owing to both the methods of harvesting and utilization, and the non-availability of markets for all wood		Sundberg, U. 1978
Surinam	• These silvicultural experiments were carried out in Surinam over a period of 30 years • Harvesting might have a similar effect of release as removing competitors around potential crop trees		• With an initial thinning of non-commercial species from 20 to 6-10 m^2 of basal area, enough volume for a harvest of 20-30 m^3/ha had grown after 20 years		• Intensive harvesting is usually more destructive for the residual stand per unit basal area removed than a silvicultural treatment in which			Buenaflor, V. & Karunatilleke, T. 1992

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					trees area killed standing by means of girdling			
Suriname	• Controlled logging found to be more efficient than conventional logging • Controlled logging reduces the impact of logging intensity • Controlled logging is less costly than conventional logging • The extra costs of planning are returned by improved operational efficiency and logging intensity on the next cycle can more or less be maintained at the same level		• Polycyclic silvicultural system on a 20-30 year cycle is most appropriate for rainforests in Suriname • Felling intensity is restricted in Suriname to not exceed 30 m^3/ha, in order to maintain the ecological, conservational and protective functions of the forest • A felling intensity of 5-8 trees/ha is considered to be sustainable for most types of tropical forests (Boerboom and Wiersum 1983) · period 1957-1970 logging intensity was 8-10 m^3/ha • CELOS silvicultural systems aim for a logging cycle of 25 years and a logging intensity of 30 m^3/ha		• 40% more felling gaps in uncontrolled logging • Skid trail area was 50% less in controlled logging areas (5.4-7.3% vs. 14.5-16%) • On average an efficient trail system should be limited to 5-8% of the area • Wood damage, involving serious loss of quality, can occur during positioning and collecting (bunching) logs with the blade of a skidder • In selection felling every effort is made to keep the remaining stand in a healthy state, by carrying out each periodic harvest with the greatest care • Wood damage was substantially higher in the uncontrolled conventional logging area (24.3-28.3% vs. 6.1-8.5%)	• Poor work methods and techniques during felling and terrain transport lead to splitting and breaking of felled trees		De Graaf, N.R., Poels, R.L.H. & van Rompaey, R.S.A.R. 1999
Suriname	• Growth rates of plantations in Suriname have not met expectations • Plantation forests should only be established where the forest has already been destroyed • If tropical rainforest are used economically, other management systems more adapted to the		• Logging intensity seldom exceeds 20 m^3/ha		• After logging the most likely impression of a visitor, walking on a skid trail shortly after conventional unplanned logging, is one of almost complete destruction			Hendrison, J. 1989

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	ecological conditions have to be developed and used (e.g., CELOS) • Commercial species account for 117.1 stems/ha (BA=10.11 m^2/ha) (dbh >10 cm) • All species account for 476.9 stems/ha (BA=25.2 m^2/ha) (dbh>10 cm)				• Damage is considerable, but the forest is not destroyed			
Suriname	• The study documents each phase of the conventional logging system, which is used almost exclusively in Suriname's small timber concessions and was applied on one sample plot at the study site. • The productivity and environmental impacts associated with this system are compared with those of planned harvesting as applied on the other sample plot in Concession 387.	• The average time required to fell a single tree was greater in the conventional logging system (8.67 min) than in planned harvesting (7.92 min) due to the time spent by the chainsaw operator (almost 10% of total time) searching for harvestable trees under the conventional system. • Skidding under planned harvesting, productivity averaged 8.15 m^3/h of workplace time, whereas skidding productivity under conventional logging averaged only 5.91 m^3/h of workplace time.			• The percentages of residual trees found damaged was 5.5% for conventional logging and 2.5% for planned harvesting. • No damage was registered during skidding operations during planned logging, whereas skidding damage was observed on the conventional logging operation. • For the planned harvesting system an average of about 5.4% of the area harvested was affected by primary skidtrails, whereas in conventional logging the corresponding value more than twice as high-12.4%. • In addition, conventional logging utilized secondary skidtrails, thus disturbing an additional area of soil which is not included in this figure. • Canopy opening by tree felling	• Timber wastage ranged between 11.7% and 15.7% on the sample plots.	• If the labour cost per cubic metre of logs delivered to the landing under conventional logging is assigned an index value of 100%, then the comparable cost under planned harvesting would amount to only 77.5%, despite the additional labour cost required for pre-harvest inventory under planned harvesting. • The substantially higher felling and skidding productivity under planned harvesting not only offsets the additional cost of the pre-harvest inventory but reduces the overall labour cost by more than 20%.	Jonkers, W. & Schmidt, P. 1984

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
					ranged from 6.5% to 7.7% of the area for the two sample plots			
Sweden	• This study presents a new approach for clustering harvest activities in time and space in long term forest planning. • The planning problem essentially consists of maximising the weighted sum of the net present value of future forest management and the clustered volume of timber to be harvested. • This objective is subject to the restriction that a certain volume should be harvested each period. • Since the spatial dimension leads to a problem that is difficult to solve with ordinary optimization techniques; the ensuing problem is solved with a heuristic technique called simulated annealing. • In a case study the suggested approach is applied to a landscape consisting of 2600 stands in southern Sweden. • The results indicate that the model is effective for clustering the harvest and that it is possible to aggregate the harvest with only a small sacrifice of the net present value.							Winkler, N. & Nobauer, M. 2001
Thailand	• A study of a teak forest 25 years after logging shows good regeneration of teak but a lack of large trees, especially in the 40-45 cm dbh class (harvest was too intense) • Average teak dbh growth in study area was 1.61 cm/a		• Selective logging of teak reduces the volume of trees (dbh >60 cm) from 100.7 m^3/ha to 9.5 m^3/ha (logging intensity = 91.2 m^3/ha) • Minimum 40 years logging cycle needed in the study area (however lower volume than initial harvest)	• Logging intensity too high • In the study area 49 of the 89 stumps were less than 60 cm dbh • Only 5 residual trees left with dbh >60 cm				Ohman, K. & Lamas, T. 2003
Uganda	• Tropical high forest • Recommends a uniform silviculture system rather than polycyclic due to excessive damage to residuals during		• Presents data for MAI of 2.1 m^3/ha/a and a logging cycle of 40 years		• Area of damage with the removal of one tree of 70 cm dbh is not likely to be less			Gajaseni, J. & Jordan, C. 1990

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
	logging				than 200 m^2 • In one study mean felling damage per tree was 405 m^2 and could have been reduced to one-half through directional felling			
Uganda	• Medium altitude tropical moist forest • Kibale Forest		• Light cut 14 m^3/ha • Heavily cut 21 m^3/ha • Annual rates of live tree falls were 1.3 trees/ha in light cut, 3.3 trees/ha in heavily cut, and 1.7 in uncut mature forest					Dawkins, H. 1958
Uganda	• Budongo Forest Reserve • Those areas logged and treated with arboricide showed a greater tree species richness per unit area than the unlogged and untreated areas (may be due to the succession towards mono-dominance that occurs in Budongo)		• Logging intensities • 1930-1939, 32.3 m^3/ha • 1940-1949, 42.9 m^3/ha • 1950-1959, 42.1 m^3/ha • 1960-1969, 25.1 m^3/ha • 1970-1979, 38.0 m^3/ha • 1980-1989, 24.9 m^3/ha	• Measures of forest structure show that more than 50 years is required for the forest to recover to pre-logging levels				Kasenene, J. & Murphy, P. 1991
Uganda	• Kibale Forest • Results indicate that levels of destruction typical of mechanized timber harvesting seriously disrupt the dynamic balance of the forest		• Maximum allowable basal area reduction in selective logging was projected to be 35% to maintain natural tree falls at an acceptable level • In unlogged area natural tree falls were 1.4 trees/year (256 stems/ha, BA 35.5 m^2/ha, canopy cover @15 m 72%) • In area with logging intensity of 14 m^3/ha tree fall rate was 1.3 trees/year 12 years after logging (267 stems/ha, BA 26.7 m^2/ha, canopy cover @ 15 m 50%) • In area with logging intensity of 21 m^3/ha tree fall rate was 6.2 trees/year 12 years after logging (125		• Conventional mechanized logging operations can destroy up to 50% of the original stand and are not a sustainable method for exploiting the Kibale Forest • Highest tree fall rate was in the heavily logged site			Plumptre, A. 1996

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
			stems/ha, BA 19.0 m^2/ha, canopy cover @ 15 m 32%)					
USA	• To examine the value of state-wide regulatory data for Massachusetts as a unique source of this critical information, 17 years of timber harvest data gathered for regulatory purposes for a 168,000 ha forested landscape in Massachusetts was analyzed. • The predominant form of harvesting was selective removal of commercially valuable tree sizes, grades and species. • The spatial pattern of logging was random with regards to major physical, biological, or cultural factors. • However, logging was strongly related to landowner class. • NIPF owners control 60% of the forest area and were responsible for 64.1% of harvest area, but the highest logging intensity (volume per area harvested; 69.3 m^3 ha-1) among major landowners was conducted by the state agency responsible for managing southern New England's largest conservation property, the watershed of Boston's drinking reservoir.		• Annual disturbance rate of 1.5% and a mean intensity of 44.7 m^3 ha-1 (approximately one-fourth of average stand volume).					Skorupa, J. & Kasenene, J. 1984
USA	• Environmentally sensitive harvesting is used to define and promote improvements in common harvesting systems. The forest industry needs to look towards new technologies and systems to provide the required environmentally sensitive harvesting techniques. • Regardless of the machinery involved, it is the people that must make the decision about what harvesting strategy to use and what equipment to employ to protect water, soil, and overall forest quality.							Kittredge Jr., D.B., Finley, A.O. & Foster, D.R. 2003

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Venezuela	• Humid evergreen tropical forest • Felling with chain saws and extraction with skidders • Tree basal area in unlogged area 32 m^2/ha, logged 23 m^2/ha, and logged with linear strip planting 20 m^2/ha		• Minimum felling dbh 40 cm • In 1988 2.9-7.3 trees/ha (5.8-14.2 m^3/ha) were authorized for extraction, but the actual rate was lower at 2.3 trees/ha (7.1 m^3/ha)					Visser, R. 2002
Venezuela	• Western llanos		• Logging intensity 14-24 trees/ha >40 cm dbh (average 18.3 trees/ha with 15.2 m^2/ha of basal area removed) • Estimated rotation age of individual trees is 80-100 years • 20 year logging cycle is proposed, with a maximum logging intensity of 7.5 m^2/ha (36 m^3/ha)					Mason, J. 1996
Venezuela	• The study was carried out in the Caparo Forest reserve which lies on the western plains of Venezuela. • Three stands logged 5, 8 and 19 years prior to sampling were selected and compared with a mature forest stand. • In each stand the area affected by logging was delimited. • The impact of logging on the stand structure and spatial pattern of commercial species was studied along a chronosequence of 5-19 year old logged stands in the Forest Reserve of Caparo, Venezuela. • For comparison, a mature forest stand was surveyed. • A systematic sampling design was applied. • Up to the mid-1980s, covered by this study, only *Bombacopsis quinata*, *Swietenia macrophylla*, *Cedrela odorata* and *Cordia apurensis* were logged.		• A polycyclic management system with a 30 year cutting cycle is prescribed in the study area. • On average 10.2 trees/ha with a bole volume of 66.5 m^3/ha were removed.	• The 5, 8 and 19 year old logged stands showed a mean basal area of 17.8, 21.3, and 22.2 m^2/ha, respectively, whereas 33.2 m^2/ha were measured in the mature forest. • The share of undamaged trees in the basal area increased from 30.8% in the 5 year old logged stand to 43.9% in the oldest logged stand. • The number of emergent trees (>30 m height) was considerably reduced by logging; even 19 years after logging only 8 stems/ha were found in this height class comparing to 51 stems/ha in the mature forest.				Plonczak, M. 1989

Location	Descriptive Information	Planning and inventory	Logging Intensity and Cycle	Residual Density and Utilization	Stand and site damage	Waste	Economic Aspects	Source
Vietnam	• Tropical low elevation and flat dipterocarp forest • Stand volume in trees >50 cm dbh was 54 m^3/ha (19 trees/ha) • Chain saw felling and tree-length skidding to landings							Kammesheidt, L. 1998
West Africa	• Limited forest land base in West Africa • Enormous pressure for its conversion to other uses • Failure of natural regeneration and increasing demand for wood make the plantation system the most logical choice for the region							Seppanen, H. & Malvas, J. 1986

APPENDIX C ANNOTATED BIBLIOGRAPHY

Abdulhadi, R., Kartawinata K. & Sukardjo, S. 1981 Effects of mechanized logging in the lowland dipterocarp forest at Lempake, East Kalimantan. *Malaysian Forester* 44(2-3): 407-418.
- 11 trees/ha were removed, with stump diameters ranging from 80 to 150 cm.
- 41% of the residual stand suffered branch and crown damage, while 59% was undamaged.
- The damaged trees were, for the most part, located close to tractor paths, skid trails and felled trees.

Agom, D.I. 1994 *Report of study on methodology and productivity of stump site chain saw timber operators*. Forestry Dept., Cross River State, Nigeria, Working Paper No. 2. 24pp.
- The average log conversion rate at the stump was 36.2%, with a maximum of 54% recorded.
- A large amount of useful wood was left in the forest because of the adherence of the dealers and buyers to specific flitch dimensions.

Agom, D.I. & Ogar, D. 1994 *Report of study on timber extraction in the Ikobi concession area in Afi River forest reserve*. Forestry Dept, Cross River State, Nigeria, Working Paper No. 3. 15pp.
- Extraction in the concession was heavily mechanized and productive, but caused considerable disturbance to the surrounding areas
- There was recorded to be 12.2% waste

Agyeman, V.K., Turnbull, C. & Swaine, M.D. 1995a *Maintenance of biodiversity in the tropical high forest: current research initiatives in Ghana*. IUFRO XX World Congress, Proceedings, Abstract. p.76-77.
- Harvesting more than 3.5 m^2/ha of basal area will exceed the forest's ability to regenerate.
- Gap sizes have an influence.

Agyeman, V.K., Turnbull, C. & Swaine, M.D. 1995b *Maintenance of biodiversity in the tropical high forest: effects of selective logging*. IUFRO XX World Congress, Proceedings, Abstract.
- Gap opening per tree felled ranged from 350-1800 m^2.
- Felling 2.6 trees/ha in the Bura Forest Reserve in Ghana resulted in 13% logging disturbance.
- Canopy gaps account for 50% of the disturbance, skid trails 38% and haul roads 12%.

Ahluwalia, S.S. & Karnasudirdja, S. 1995 Notes on lesser-used species in Malaysia and Indonesia. *ITTO, Tropical Forest Update* 5(2): 10.
- Logging intensity in Malaysia has increased from an average of 24 m^3/ha (1971-78) to 45 m^3/ha (1979-90).

Ahmad, S., Brodie, J.D., & Sessions, J. 1999 Analysis of two alternative harvesting systems in peninsular Malaysia: Sensitivity analysis of costs, logging damage and buffers. *Journal of Tropical Forest Science* 11(4): 809-821.
- The study was carried out in hill dipterocarp forest in eastern Peninsular Malaysia.
- Selective Management System with rotation length of 30 years.
- Cutting limit 45-50cm dbh.
- New system incorporates directional felling and improved road construction.
- Skidding efficiency has improved under the new system.
- Comparison of logging costs (cost reduction of 4%):

Activity	New System (US$/$m^3$)	Traditional System (US$/$m^3$)
Felling and cross-cutting	1.26	1.63
Skidding	2.88	2.90
Loading and unloading	0.66	0.25
Short hauling	2.29	2.79
Supporting costs	6.31	6.35
Total logging costs	13.39	13.92

- Under the new system 30% of the total volume was damaged during harvesting. With a discount rate of 4%, the damage equals 61.92 US$/$m^3$.
- Under the traditional system it is assumed that 40% of the total volume are damaged during harvesting. With a discount rate of 4%, the damage equals 85.88 US$/$m^3$.

Ahrenholz, T. 1991 *Die Erschliessungssituation bei der Nutzung tropischer immergruener Feuchtwaelder in Ostkalimantan; Indonesien- eine Fallstudie an einem Beispielsbetrieb*. University of Goettingen. Diploma thesis. 123pp.

- This study was carried out in eastern Kalimantan, Indonesia.
- The commercial volume of primary forests in this region is 101.9 m^3/ha for trees >20cm dbh.
- In plantation forests, 200m^3/ha of commercial timber could be produced on a 12-year rotation.
- The following cutting cycles are proposed: saw logs 20-30 years, pulpwood 8-20 years, fuelwood 5 years.
- Two harvesting systems were evaluated: the TPI system (Indonesian Selection System) and the HTI system (clear felling and artificial regeneration).
- Directional felling is not possible with the equipment currently available.
- The following data were found for stem volume and log waste (Radtke, 1990):

	Stem volume (dbh >15cm) (m^3/ha)	**Volume utilized (m^3/ha)**	**Log waste (m^3/ha)**
Trees felled	128.8	76.2	52.6
Felling damage	23.8	-	23.8
Total	152.6	76.2	76.4

- On the study site, the volume extracted was equal to the volume damaged or left behind.
- On average, 10 harvestable trees were found per hectare (79.40 m^3/ha).
- The average road density was 18.34 m/ha (3.25m of primary roads per hectare); the average skidding distance was 163.4m.
- Between 25 and 48% of the skid trails were traversed 4 to 8 times during harvesting operations.
- The average skidding costs were US$ 2.2 to 2.5 per cubic metre.
- In the study area, 5.4% of the area was affected by roads (primary roads 1.6%, secondary roads with water bound surface 0.5%, temporary secondary roads 3.2%).
- On average, 20.7% of the area was affected by skidding (26.8 m^2 were affected per cubic metre of timber extracted).
- According to RADTKE 1990, 14% of the area was covered with logging debris after felling.

Andel, S. 1978 *The impact of harvesting systems on tropical forest management in South East Asia*. Food and Agriculture Organization of the United Nations, Final Report MAL/75/012.

- Proper logging in West Malaysia may add M$51-70/ha, whereas post logging silvicultural treatments (including planting of roads and landings) may cost about M$200/ha.

Andrewartha, R. 2002 Improving forest harvesting practices through training and education. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- Tasmania has pioneered improvements in forest operations within the Australian forest industry, with the introduction of the Forest Practices Act in 1985, of which the Forest Practices Code (FPC) is an integral part.
- The code outlines minimal environmental standards that must be achieved for all forest operations, including guidelines to reduce the impact of logging.
- The Vanuatu Code of Logging Practice (VCOLP) was introduced in 1998, using the existing Forestry Act as the basis for legislation (Vanuatu Department of Forests, 1997a).
- Full compliance with all operating standards was to be achieved by 31 December 2000.
- Complementary to the code, reduced impact logging (RIL) guidelines were formulated designed to assist field supervisory staff and industry operators in executing forest-harvesting plans (as required by the VCOLP).

Andrewartha, R. 1998 Reduced-impact logging developments in Sabah. *ITTO Tropical Forest Update* 8(1): 24-26.

- No blading-off of soil on skid tracks less than 15º side slope.

Appanah, S. & Putz, F.E. 1984 Climber abundance in virgin dipterocarp forest and the effect of pre-felling climber cutting on logging damage. *Malaysian Forester* 47(4): 335-342.

- 13 ha study area had 376 climbers/ha >2 cm dbh.
- Cutting climbers before logging reduced the number of trees pulled down during felling by about 50%.
- Half of the climbers not cut prior to logging survived felling of their host trees and sprouted vigorously.
- Poisoning cut climbers with 2,4,5-T usually prevented coppicing.

- Climber cutting and poisoning productivity was 1 ha per 5 work hours.
- Concluded that climber cutting prior to felling was a worthwhile silvicultural operation.

Appanah, S., Weinland, G., Bossel, H. & Krieger, H 1990 Are tropical rain forests non-renewable? An enquiry through modelling. *Journal Tropical Forest Science* 2(4): 331-348.

- Simulations show that a 35 year cutting cycle may be too low in the selective management system (dipterocarps >60 cm dbh removed, nondipterocarps >45 cm dbh removed, logging cycle 35 years).
- For the SMS 35 year cutting cycle, the logging results in continuous reduction in harvest of emergents after every successive cutting.
- Another critical point stands out clearly - in all simulations the pole regeneration is ephemeral in time and space. There is a clear danger in this: if cutting occurs when the poles are small in number or absent, then no residual stand will develop for the third cut.

Appanah, S. & Manaf, M.R.A. 1990 Smaller trees can fruit in logged dipterocarp forests. *Journal of Tropical Forest Science* 3(1): 80-87.

- A comparison of fruiting ability of dipterocarps in a recently logged forest with that of an undisturbed and old regrowth forest.
- In the recently logged forest the small dipterocarp residuals (>25 cm dbh) could fruit (i.e., to produce seedlings for the 3rd cycle).
- By comparison, equivalent sized trees in the old regrowth and undisturbed forests did not; here fruiting trees were >35 and >50 cm dbh, respectively.
- Results suggest that dipterocarp forests are potentially capable of regenerating within a few years after logging, on the condition sufficient advanced residuals are present.

Appanah, S. & Weinland, G. 1990 Will the management systems for hill dipterocarp forests, stand up? *Journal of Tropical Forest Science* 3(2): 140-158.

- This paper describes the Selective Management System (SMS) of Peninsular Malaysia Hill forests in Peninsular Malaysia, the Indonesian Selective Cutting System (ISCS), and the Philippine Selective Logging System (PSLS).
- SMS consists of a logging cycle of 25-30 years, and the minimum economic cut is presently at 30-40 m^3 /ha of currently commercial and utilizable species:
    - SMS and selective fellings are the principal management systems for dipterocarp forests throughout Southeast Asia, although, some lowland dipterocarp forests are still being managed under the Malayan Uniform System (MUS).
    - In the SMS all commercial species above 45 cm for non-dipterocarps and 50 cm for dipterocarps are felled, while maintaining minimum stocking levels of trees/ha in >45 cm, 30-45 cm and 15-30 cm classes. There is also a sequence of post harvest operations that should be carried out (e.g., pre-felling inventory, climber cutting, tree marking)
- In the PSLS a logging cycle of 30-40 years with suitable tending is used.
    - During the first silvicultural operation only 30% of trees with dbh between 15-65 cm and 60% of trees of 65 cm dbh and over may be felled.
    - In the Mindanao area yields have been 100-120 m^3/ha but such high yield forests have dwindled quickly.
    - For PSLS to be successful need an effective monitoring system and logging damage must be drastically reduced.
    - At present the logging intensity is 70-90 m^3/ha on a logging cycle of 35-40 years, but it is felt this should be corrected downwards or the cutting cycles extended (Lamprecht 1989)
- The ISCS is a much simpler system than the PSLS.
    - The forests in East Kalimantan are much poorer than those in the Philippines, so only 10-15 stems/ha (about 100 m^3/ha) are extracted.
- Important to all selective cutting is to retain sufficient numbers of trees in the 30-45 cm dbh class that will form the trees harvested in the second rotation. Also, sufficient seed trees are needed to regenerate the area.
- However, all the necessary silvicultural treatments, directional felling, protection of advance growth, proper selection of trees to not reduced genetic quality of the forest, etc. are not currently done, so the current selective systems are not sustainable on a 35-40 year cutting cycle.
- The lack of linkage between logging operations and silviculture considerations is potentially destructive to the forest; more is left to chance than to design.

- Many studies refer to an average diameter growth rate of 0.8-1.0 cm/year. These references generally link back to a UNDP/FAO project in 1978, which has been criticized by Wyatt-Smith (1988) as being of dubious nature.
- While these growth rates of vigorous individuals may be possible on the best sites, on average, it is unlikely that dipterocarp forests of Malaysia can reach these growth rates (gives values from yield plots ranging from 0.3-0.9 cm/year.
- In SMS logging damage to residuals is estimated at about 30% for trees above 30 cm dbh, however, in many cases this is exceeded and it does not take into account mortality occurring several years after logging.
- Another problem is that the selective system is applied everywhere without taking into account the condition of the stand (growth potential, tree form, damage, adequacy of numbers); it should be an option which is applied where most suited and a varied of systems should be employed.
- For SMS to work, firstly and of immediate concern is the improvement of logging practices.

Applegate, G.B. 2002 Financial costs of reduced impact timber harvesting in Indonesia: case study comparisons. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- Four case studies were conducted in similar dipterocarp-dominated lowland and hilly forests in East Kalimantan, Indonesia.
- The studies were undertaken in Berau; Kutai Induk (near Kutai National Park); PT Sumalindo Lestari Jaya IV concession and the Center for International Forest Research (CIFOR) Bulungan Research Forest, Malinau District.
- The analysis compared the costs of the components measured in the four studies.
- The selected RIL studies had the felling compartments outlined in the harvesting plans, which were based on accurate topographic maps of between 1:2 000-5 000 scale, with contour intervals of between 5 and 10 m.
- The harvesting plans identified planned skid trails and landings and individual tree locations.
- Most CL activities on the sites used for the case studies did not have adequate maps for implementing harvesting activities.
- There was no planning of skid trails, and directional felling techniques were not employed.
- RIL produced a reduction (almost 50 percent) in the damage caused to the residual stand.
- The results from the cost analyses are inconsistent.
- The observed inconsistencies and differences do not allow for comprehensive and meaningful comparisons.

Armstrong, **S. & Inglis, C.** 2001 Addressing the gap between the theory and practice of reduced impact logging. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- Research undertaken in a commercial harvesting operation in Guyana indicates that Reduced Impact Logging (RIL) improves efficiency, reduces unit cost of production at both the harvesting and operational scale and reduces damage to the forest. Strengthening management systems and changing attitudes were particularly important in improving harvesting practice. Following the research, those recommendations which involved least risk to the company and which were simple and robust were most readily adopted into commercial practice.
- Lessons from this work are projected into other operations. It is argued that improvements in harvesting practice are unlikely where harvesting guidelines or targets are set without also planning and managing the necessary change within harvesting operations. Importantly, the different interest groups within commercial operations will each need to have reason to support RIL, and to be actively in its development, if it is to be successfully adopted.
- Despite the growing body of literature which indicates that RIL is cost effective, its uptake by industry seems to be limited. The reasons for this are explored and it is proposed that the key reasons include poor communication, the use of inappropriate terminology and differing perspectives between researchers and commercial operators.

Armstrong, S. & Inglis, C.J. 2000 RIL for real: introducing reduced impact logging techniques into a commercial forestry operation in Guyana. *International Forestry Review* 2(1): 17-23.
- Commercial species were *Baromalli* and *Trysil* (12% of basal area).
- The harvesting intensity was 8.2 m^3/ha (2.4 trees per hectare).

- Vine cutting took place 6 months before harvesting; it was only feasible to cut those around trees identified for harvesting.
- A tendency to produce an inefficient skid trail design exists where no pre-harvest tree location map is used.
- With conventional logging practices the volume lost as waste wood was 3%.
- Observations suggest that trained and experienced fellers can reduce the incidence of wood loss significantly.
- With RIL, no merchantable trees were missed in the block.
- The time requirement for conventional felling was 3 minutes/tree, for directional felling it increased to 7 minutes/tree.
- A 30% reduction of skid trail length seems possible by providing a tree location map, basic training and increased supervision.
- RIL techniques reduced the bulldozer time for positioning the log for extraction from 8 to 2.5 hours/100 logs.
- Additional costs are associated with the pre-harvest inventory required for RIL.
- If the value of the increase in production is taken into account, the adoption of RIL significantly reduces the production costs per m^3.
- At the company level, increased production per block reduces the area of forest needed per m^3 harvested; additional cost reductions are achieved in road construction, maintenance and hauling costs per m^3 produced.
- The most severe damage resulted from the use of bulldozers (skid trail construction, positioning of log for extraction).
- Damage caused by clearing trees with attached vines during skid trail construction was significant.
- Fellers are proficient at identifying the most common commercial species; therefore training fellers in spotting other commercial species should reduce the volume lost in this way.
- Improved efficiency of skid trail construction implies reduced damage and reduced cost at the operational scale.
- An instructive exercise for any commercial operation will be to assess the quantity of merchantable wood left in a recently closed harvesting area as well as the extent and layout of skid trails.

Aulerich, D.E. & Sirait, J. R. 2002 Forest harvest training – the Sumalindo project. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- PT. Sumalindo Lestari Jaya is an integrated wood-based industry company headquartered in Jakarta, Indonesia. It is operating in the natural forests in East Kalimantan.
- This project addressed road construction activities in the swamps of East Kalimantan, and conducted analysis of the logistics of all harvesting options and activities. ▪ The objective was to conduct cost-effective harvesting operations while reducing impacts on the environment.
- After the initial evaluation of the ongoing operations, cable logging (primarily skylines) seemed to provide the most promising alternative for improving production, decreasing costs and reducing environmental impacts. The primary reasons for this conclusion were the steepness of the terrain, the high rate of soil erosion and the heavy rainfall, which could shut down tractor operations. ▪ Workshops were organized to introduce top management and middle management to the alternatives to the basic ground-based systems being applied.
- Meetings were also held with the regulatory agencies and operations people were then identified for training programs.

Ayres, J.M. & Johns, A.D. 1987 Conservation of white uacaries in Amazonian várzea. *Oryx* 21(2): 74-80.
- Current average extraction rates of 4-5 trees/ha have caused a total loss of only about 5% of standing trees in resting as (narrow interlinked corridors of trees located on alluvial levées where trees are felled during the low water period and floated out during high water).
- In nearby terra firme forest, removal of the same number of trees causes a total loss of 60% due to the heavy logging equipment, landings and roads.

Bach, C. F. 1999 Economic incentives for sustainable management: a small optimal control model for tropical forestry. *Ecological Economics* 30: 251-265.
- This model analyses several options to make it profitable for the concessionaire to undertake low impact logging activities (without any further control).
- The model is based on an average concession of 10,000 ha in Ghana.
- The concession is operated on a 40-year felling cycle.

- Cost data in this model stem from a detailed survey of one of the largest timber companies in Ghana.
- Revenue data are based on a survey of prices and end-uses for all timber species.
- Around 1/3 of the trees >50cm dbh are allocated for harvest; the growing stock of commercial species is fairly low.
- There is a lack of economic incentives for the concessionaire to introduce RIL techniques.
- The implementation of RIL techniques would require additional investments in planning, training and the construction of roads and trails.
- Economic incentives could be established either through direct area-dependent payments or through higher prices.
- Logging without any consideration of future growth will damage 40% of the stand, conventional logging as practised in Ghana will damage 30%, while reduced impact logging will damage only 20% of the stand.
- Costs are assumed to consist of fixed costs per hectare and variable costs depending on the amount harvested. The variable component covers all variable costs in extraction, hauling and processing.
- The highly volatile exchange rate of cedis to US$ has a major impact on the absolute profitability in production. However, the relative profitability remains unaffected.
- Increased costs in sustainable management often stem from activities such as training, mapping, inventories and proper construction of skid trails and roads. These costs will be mostly independent of the volume extracted.

- Simulation and results for net present value:

	Net present value (US$ million)
Simulation 1: base-line. Yield allocation. Discount rate 5%. No subsidies.	1.51
Simulation 2: low damage. Yield allocation, Low damage level imposed. No subsidies.	0.81
Simulation 3: area-dependent subsidy. Yield allocation. Direct area-dependent subsidy to effort of US$ 92.5/ha. High effort level maintained in the first 60 years.	1.51
Simulation 4: price subsidy. Yield allocation. Price subsidy of 147%. High effort level maintained in the first 60 years.	26.68
Simulation 5: no yield allocation. No yield allocation. No subsidies.	1.65
Simulation 6: discount rate of 10%. Yield allocation. No subsidies. Discount rate 10%.	0.99

- Simulation 2: The concessionaire would certainly attempt to avoid the extra costs. A tension occurs between short-term profitability and long-term sustainability.
- Simulation 3: It is possible to persuade the concessionaire to reduce damage with an area-dependent subsidy of US$ 92.5/ha. At effort costs of US$ 9/ha there is no reduced impact logging, because the benefits only occur 40 years later. At a discount rate of 5%, the net present value of these benefits is marginal.
- Simulation 4: If the price of the effort to reduce damage is set to one, prices must be raised by 147% in order to persuade the concessionaire to implement reduced impact logging. This is equivalent to an additional US$ 3,157/ha for the first year. The concessionaire will not compare his net present value with a price subsidy with that seen in the base line, but only with the net present value if he received the price subsidy but continued with a low effort and a high damage level.
- Simulation 6: An increase in the discount rate will increase the incentive to fell a larger area and/or higher volume per hectare and thus increase the risk of unsustainable management practices.
- Without compensation it will be difficult to impose even small additional costs in harvest operations.
- There is no reason to undertake low impact logging practices if no future harvest is expected on the area (e.g. because of an expiring concession). In these cases, at the end of the concession period the forest has no value for the concessionaire.
- The growing stock of the most valuable timber species is improved by 30-50% if reduced impact logging is introduced.
- Target subsidies fit well into the current institutional set-up, encompassing logging manuals, detailed topographic maps, post-harvest inspections and royalty collections.
- Subsidising the costs connected with reduced impact logging through area-dependent subsidies is by far more efficient than subsidising prices of tropical timber.

- Marn and Jonkers (1981) find that in Sarawak, conventional logging will severely damage 60 trees/ha of commercial species (harvesting intensity 13.33 trees/ha). With well planned, supervised harvesting and directional felling the loss will be reduced to 40 trees/ha. With a harvest intensity of 2 trees/ha, the loss due to damage is 9.5 trees/ha. 80% of the damaged trees are in the diameter class of 10-40cm.

Baharuddin, K., Mokhtaruddin, A.M. & Nik Muhamad, M. 1995 Surface runoff and soil loss from a skid trail and a logging road in a tropical forest. *Journal of Tropical Forest Science*. 558-569.
- Study in the tropical forest of Malaysia, and total annual rainfalls for the two-year study period were 3084 and 2308 mm/year, respectively
- Results from a two-year study revealed that the average surface runoff from the undisturbed forest, skid trail and logging road were 62.9, 391.4 and 545.2 mm/year, respectively; the values correspond to 2.3, 14.5 and 20.3% of the total rainfall
- The surface runoff generated 453.7, 10069.7 and 13340.7 kg/ha/year of soil loss from the undisturbed, skid trail and logging road, respectively in the first year after logging
- In the second year soil losses decreased by 80% to 211.3 kg/ha/year for the skid trail and by 77% to 3146.7 kg/ha/year for the logging road
- Drastic reduction in the soil loss was probably due to the rapid recovery in soil stabilization arising from fast re-establishment of ground cover and emergence of seedlings on the logging road and skid trail
- Plant and litter cover were shown to be the greatest deterrent to surface erosion|
- Soil losses in the logging road and skid trail increased up to a 20% slope, after which there was a rapid increase in soil loss; recommended that skid trails and logging roads not be constructed on slopes exceeding 20%

Baidoe, J.F. 1970 The selection system as practiced in Ghana. *Commonwealth Forestry Review* 49(1): 159-165.
- Selection system as practiced in Ghana in 1970 dates from 1956.
- It should involve stock mapping (detailed mapping of location and description of all commercial trees) of all economic trees >7 foot girth (68 cm dbh), improvement thinning of immature trees, vine cutting and selective cutting on a 25 year cycle.
- 26 out of 190 tree species that grow to timber size are economically valuable.
- 2.5-5.0 trees/ha that are exploitable.

Balachandra, L. 1988 Buttresses on trees of Andaman and Nicobar Islands. *Journal of the Andaman Science Association* 4(2): 124-127.
- The volume of timber remaining in the forest in the form of buttressed stumps was 8.2 m^3/ha for `hardwoods' and 5.89 $m^3$/ha for `softwoods'.
- Removal of buttresses before felling would minimize timber damage, increase timber yield and keep the forest floor in a more hygienic condition.

Barreto, P., Amaral, P., Vidal, E. & Uhl, C. 1998 Costs and benefits of forest management for timber production in eastern Amazonia. *Forest Ecology and Management* 108 (1-2): 9-26.
- Current logging practices in eastern Amazonia are careless, resulting in much unnecessary damage.
- This study compared the net present value for 20- and 30 year cutting cycles with and without forest management (planned and unplanned logging operations).
- The costs to plan logging operations were estimated at US$ 72/ha or approximately US$ 1.80 to 2.50 per m^3 for harvesting intensities of 35-40 m^3/ha.
- More than 90% of the planning costs occurred in tree mapping, vine cutting, and planning logging manoeuvres (skid trail layout, felling angle determinations).
- The careful planning of tree felling operations resulted in a 15% increase in productivity (m^3 felled /work hour) when compared to unplanned harvesting operations.
- The machine time (min/m^3 harvested) necessary to open logging roads and log landings was 37% less in the planned operation than in the unplanned operation.
- The productivity of skidding logs to landings (m^3 hauled/hour) was 27% greater in the planned operation using wheeled skidders, compared to standard bulldozer-based extraction in unplanned operations.
- In absence of planning 26% of the felled volume of timber was wasted (7% due to poor felling techniques, 19% simply lost because felled trees were never found by the tractor operator).
- Using RIL techniques only 1% of the felled timber was wasted.
- Overall, increased work productivity and reduced waste in the RIL operation resulted in financial benefits of US$ 3.7 per m^3, which was approximately two times the cost of planning.

- RIL techniques reduce damage to the forest, leaving a well-stocked stand.
- Good residual growing stock combined with silvicultural treatments following logging should result in greater timber production in managed forests.
- It was estimated that with forest management 68% more timber volume could be extracted over a 30-year period than without management. Using discount rates ranging from 6 to 20%, the estimates of the net present value of timber extraction with forest management were 38 to 45% higher than without management.
- However, any investment in forest land is perceived as risky because of frequent disputes over land ownership.

Bariteau, M. & Geoffroy, J. 1989 Sylviculture et regeneration naturelle en foret Guyana's (Silviculture and natural regeneration in the forests of French Guinea). *Revue Forester Franchise* 41(4): 309-323.
- The study of regeneration under three logging intensities.
- Average volume in area (dbh _ 10 cm) was 350 m^3/ha with a basal area of 31 m^2/ha.
- The base treatment removed 33 m^3/ha (2.6 m^2/ha BA).
- Other treatments removed various amounts for fuelwood and through herbicide treatment.

Barros, A.C. & Uhl, C. 1995 Logging along the Amazon River and estuary: patterns, problems and potential. *Forest ecology and management* 77: 87-105.
- Para State.
- Well-capitalized wood industries go as far as 500 km into the forest in search of mahogany (Verissimo et al., 1995).
- Paper outlines logging techniques used.
- Small mill (circular saw, family run, n=60) producing rough saw wood, generally for local markets, required on average 1850 m^3 of logs for 650 m^3 of sawn wood per year (= 35.1% LRF).
- Medium size mills (generally one band saw, 30 people employed, n=41) required on average 10200 m^3 of round wood to produce 3500 m^3 of sawn wood (= 34.3% LRF).
- Veneer and plyboard mills (n=5) 91000 m^3 for 33850 m^3 of processed wood (=37.2% yield), logs floated from as far as 2500 km away.
- In the varzea forest the average logging intensity is 56 m^3/ha/entry (N. Maciel, pers.comm. 1994).}
- In the terra firme forest the average logging intensity is 38 m^3/ha/entry (Verissimo et al. 1992).

Bennet, C. P.A. 2002 Outcome-based regulations to encourage reduced impact logging. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- Widespread adoption of reduced impact logging (RIL), particularly in tropical forests, will probably remain an elusive goal wherever the forestry policy environment is overly prescriptive, dictating how to achieve sustainable forest management (SFM).
- Instead, the focus should be on forest management outcomes that allow site-specific adaptations as well as sufficient regulatory oversight.
- Forestry policy development in Indonesia from 1967 to 1999 illustrates the policy problem as well as opportunities to advance RIL.
- This paper argues that the basic problem has not been lack of enforcement and implementation but the nature of the policy framework itself.
- Prevalent, and often counter-productive, prescriptive regulations should be reoriented towards outcome-based policies to promote RIL as well as other aspects of SFM.

Berthault, J.G. & Sist, P. 1997 An experimental comparison of different harvesting intensities with reduced impact and conventional logging in East Kalimantan, Indonesia. *Forest Ecology and Management*: 209-218.
- Study comparing conventional to RIL logging.
- Original density 530 +- 63.3 stems/ha; BA 31.4 +- 3.2 m^2/ha.
- Harvest ranged from 5 to 15 stems/ha (43 to 174 m^3/ha or 9.8 to 30 m^2/ha).
- Felling mainly injured trees (especially crown damage to trees 30-50 cm dbh), whereas skidding was the main cause of mortality (especially uprooting and to trees 10-20 cm dbh).
- There was a higher percent of damage to trees in the middle size classes; 74.5% of trees killed were 10-20 cm dbh, but this class only holds 63% of trees.
- RIL reduced damage or death to trees from 48.4% to 30.5% (i.e., extra 95 trees/ha >10 cm dbh remained undamaged).
- In Borneo, damage often exceeds 50%, which is more than in Africa or South America.

Bethel, J.S. 1984 Sometimes the word is "weed": a critical look at lesser-known species. *Unasylva* 36: 17-22.

- Lesser known species or secondary species is a phenomenon wherever "forest exploitation" as a method of forest use occurs.
- Forest exploitation involves the search for merchantable species and specimens from among the trees that happen to occur in natural or secondary forests.
- Forest management, on the other hand, involves growing trees that are known to be merchantable.
- When the exploitative use of the natural forest does not provide enough products to meet the demands of society, it may become both feasible and desirable to grow a crop of trees in a managed forest to serve as raw material for a forest-utilization system responsive to social preference.
- When the quantity of preferred trees becomes scarce, there is always the temptation to augment the timber production by attempting to market less-preferred species.
- Utilization level of some humid tropical forests in Southeast Asia and Latin America varies from 4 to 48 m^3/ha.
- When timber is harvested from exploitation forests, the final yield of product from a tree is often as low as 10 to 20% and typically averages no more than 30%.
- Forest inventory practices often include utilization standards that are totally unrealistic in terms of commercial feasibility.
- Failure to recognize that most tree species in a mixed-species tropical-hardwood forest occur so infrequently, intermittently and irregularly in a harvesting operations that it is virtually impossible to develop around them a viable product-manufacturing operation.
- There is too much wishful thinking on the prospects for developing instant new markets for previously unknown and unmerchantable species.
- There are often too many unrealistic expectations about the impact of new manufacturing technology on the utilization of currently unmerchantable woods.
- New manufacturing technology is typically developed to improve the use and merchantability of woods that are currently well known and accepted in the market.
- Manufacturing processes that are indiscriminate with respect to species are usually also those that require very large capital investments - something that is sometimes not readily available in developing countries.
- Usually more economically advantageous to supply a mill with a uniform raw material, even though it may be able to handle mixed species.
- There has been major success in the use of underutilized species: e.g. western hemlock for pulp, aspen in OSB and pulp, birch in pulp.
- The danger in placing too much emphasis upon the development of new products from currently unused or under-used secondary species is that it provides an excuse for allowing productive forest land to be occupied by weeds on the remote chance that tomorrow they will not be weeds (also feel there is no need to regenerate the desirable species - poor management and sustainability of operations in the forest).

Bhargava, S.K. & Kugan, F. 1988 *Development of forest sector planning, Malaysia: assessment of logging waste and mill residues in Sabah.* Food and Agriculture Organization of the United Nations, United Nations Development Program, FO:DP/MAL/85/004, Working Paper 4. 26pp.

- Study of stump area logging waste in previously unlogged and logged forests in flat, medium and difficult terrain in Sabah. On average the waste amounted to 18.3% of the actual log production (Bhargava and Kugan 1988). Bhargava and Kugan (1988) also found that on average 9.4% of the actual log production was left as residues in the landings, and that almost 54% of the residue logs observed were free of any defects. The total utilizable waste based on removed log volume was 27.7%.
- Of a total harvest of 9.81 million m^3 (1986), 2.72 million m^3 is utilized waste left in the forest.
- Logging residues were all pieces of timber >2 m in length and >45 cm diameter.
- The cm dbh diameter felling limit =114,520,000 m^3.
- If 40 cm dbh felling limit the volume would be 169,000,000 m^3.
- Plantations of cocoa, rubber and oil palm expected to yield 30-40 m^3/ha/year.
- Sawmill recovery 50% and waste 50% (edges 12%, slabs 14%, off cut 7%, sawdust 12% and bark 5%).
- Plywood mill recovery 44% plywood, wood residue 45% (log trim 4.4%, cores 5.9%, undried veneer 24.1%, dried veneer 8.5%, sander dust 2.1%), bark 11%.
- Of 1.9 million m^3 fed to sawmills, and veneer and plywood mills, 0.68 million m^3 are left as un-utilizable.
- Total usable logging waste and mill residues amount to 3.4 million m^3 annually.

Blanche, C.A. 1978 An overview of the effects and implications of Philippine selective logging on the forest ecosystem. *BIOTROP Special Publication* 3: 97-109.
- The Philippines, motivated by an overwhelming desire to curb the rapid depletion of her forests, has embarked on "selective logging system" as a means of achieving sustained yield.
- Theoretically any silvicultural system is sound; it is when abused, misused and overused that damages occur.
- Increasing horsepower utilization is directly related to the degree of forest devastation.
- Regeneration of dipterocarps in a mixed dipterocarp forest (Quezon) is enhanced by the conditions present in a properly logged forest.

Blate, G.M., Putz F.E. & Zweede, J.C. 2002 Progress towards RIL adoption in Brazil and Bolivia: driving forces and implementation successes. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- Many companies in Bolivia and Brazil have made substantial progress toward the adoption of RIL practices between 1995 and 2000.
- Large, diversified and well-organized companies have progressed most in this regard.
- In general, these companies have adopted the RIL elements that increase efficiency, reduce costs, improve marketing and enable companies to comply with the law.
- Still lacking is implementation of the RIL elements that particularly benefit the forest, including directional felling and skid trail layout to protect future crop trees, minimal impact skidding and watercourse protection.
- Many factors influence the degree to which companies are adopting specific RIL elements and these differ somewhat between Brazil and Bolivia.
- In Bolivia, improving market access by becoming certified is probably the most important reason why companies have adopted many RIL practices.
- In Brazil, the most important factor driving RIL adoption has been the increased efficiency and cost savings derived from the adoption of the planning elements of RIL.

Blate, G.M., Putz F.E. & Zweede, J.C. 2001 Changing harvesting practice in the Amazon. *ITTO Tropical Forest Update* 11(2): 8 – 9.
- Forest owners and operators in Brazil and Bolivia were interviewed in order to assess the level of implementation of RIL in the two countries.
- In Bolivia the companies making the most progress towards RIL implementation are large, well organized and vertically integrated; whilst in Brazil those companies making most progress towards RIL adoption are those with enough capital to invest in appropriate technology and training of personnel.
- Companies in Brazil and Bolivia have adopted the RIL elements that increase efficiency, reduce costs, enable them to comply with the law, and help them improve marketing.
- In Bolivia, improving market access through certification is probably the most important reason for RIL adoption whilst in Brazil, increased operational efficiency and consequent cost savings.
- Two of the main obstacles facing RIL implementation in both countries is the perception that RIL is prohibitively expensive and the lack of trained people at all levels.

Blate, G. 1997 Sustainable forest management in Brazil. *Tropical Forest Update* 7(3): 14-15.
- This article summarises key findings of the IMAZON low impact logging study.
- In conventional logging 7 m^3/ha of wood were lost during skidding operations by not finding all felled trees while 0.3 m^3/ha were lost due to poor felling and bucking practices.
- Brazilian producers could yield an additional 7.3 m^3/ha by introducing reduced impact logging.
- Reduced impact logging damages 30% fewer trees and disturbed 25% less of the canopy than conventional logging.
- With reduced impact logging, 5% of the area harvested were disturbed by skid trails, roads and log decks.
- Reduced impact logging practices reduced the machine time by 20%.
- Reduced impact logging practices may also reduce cutting cycles by more than half. A harvesting cycle of 70 years for conventional methods may be reduced to 25-30 years through reduced impact logging.

Boerboom, J.H.A. & Wiersum, K.F. 1983 Human impact on tropical moist forest. *In*: Hozner, W., M.J.A. Werger and I. Ikusima (eds.). *Man's Impact on Vegetation*. Junk Publishers, The Hague, The Netherlands.
- A felling intensity of 5-8 trees/ha is considered to be sustainable for most types of tropical forests

BOLFOR, IURFO, CIFOR. 1997 *Aplicación de la regencia forestal al manejo y aprovechamiento del bosque natural: caso de Costa Rica*. BOLFOR, IUFRO, CIFOR. Santa Cruz de la Sierra.
- This study was carried out in the natural forests of Costa Rica.
- The harvesting intensity for the first harvest in natural forests ranges from 40 to 60 m^3/ha.
- Secondary forests are managed on a 15-year cutting cycle with a harvesting intensity of 20 to 30 m^3/ha.
- Additional costs are associated with the implementation of RIL ("buen manejo forestal") techniques.
- A polycyclic system was established in order to maintain irregular structure and species diversity.
- Up to 60% of the commercial volume may be extracted with a minimum harvesting diameter of 60cm dbh.
- Silvicultural treatments will be applied if necessary.

Boltz, F., Holmes, T.P. & Carter, D.R. 2003 Economic and environmental impacts of conventional and reduced-impact logging in tropical South America: a comparative review. *Forest Policy and Economics* 5: 69 – 81.
- Indicators of environmental impact and financial performance are compared for case studies of tropical forest logging from the Brazilian Amazon, Guyana and Ecuador.
- Each case study presents parameters obtained from monitoring initial harvest entries into primary forests for planned, reduced impact logging (RIL) and unplanned, conventional logging (CL) operations.
- Differences in cost definitions and data collection protocols complicate the comparative analysis, and suggest that caution is necessary in interpreting results.
- Given this caveat, it appears that RIL can generate competitive or superior profits relative to CL if the financial costs of wood wasted in the harvesting operation are fully accounted for.
- Increased operational efficiency is an important benefit of RIL, one that largely determines its cost-effectives relative to conventional practices.
- Uncertainties concerning the marginal benefits of RIL relative to familiar, profitable conventional practices pose an obstacle to broader adoption.
- Moreover, CL firms face few incentives to alter their operation unless they face dramatic changes in market signals.
- Adoption of RIL techniques as part of a long-term forest management regime faces additional challenges related to the opportunity cost of silvicultural prescriptions and timber set-asides to maintain productivity and ecosystem integrity.

Boltz, **F., Carter, D., Holmes, T. & Pereira Jr**., **R.** 2001 Financial returns under uncertainty for conventional and reduced-impact logging in permanent production forests of the Brazilian Amazon. *Ecological Economics* 39: 387 – 398.
- Reduced-impact logging (RIL) techniques are designed to improve the efficiency of timber harvesting while mitigating its adverse effects on the forest ecosystem.
- Research on RIL in select tropical forest regions has demonstrated clear ecological benefits relative to conventional logging (CL) practices while the financial competitive-ness of RIL is less conclusive.
- A comparative analysis of financial returns to one and two cutting-cycle logging entries for representative RIL and CL operations of the eastern Amazon was conducted.
- Observed variability in harvest efficiency and uncertainties of forest productivity are introduced in a stochastic simulation of future biological and financial returns to the alternative logging systems.
- Despite the perceived investment risks, RIL harvesting operations generate competitive or superior returns relative to CL for a wide range of discount rates due to gains in harvest efficiency and forest conservation.

Borhan, M., Johari, B. & Quah, E.S. 1987 Studies on logging damage due to different methods and intensities of harvesting in hill dipterocarp forest of Peninsular Malaysia. Malaysian *Forester* 50: 135-147.
- Logging with tractor and high-lead logging systems (each with three minimum diameters between 45 and 60 cm dbh) in Peninsular Malaysia compared for damage to seedlings, advance growth and soil.
- Damage to seedlings in high-lead areas (50-57%) was higher than in tractor-logged areas (38-48%).
- In the latter mortality was highest in the lowest size cutting limits.
- Tractor damage at 60 cm min dbh led to disturbance of 17.81% of the soil area.
- Damage to trees >10 cm dbh was higher with high-lead logging (24%, 26%, 38 % with 45,60,52 cm min. cutting limits).
- With tractors damage to these trees ranged from 8% (45 cm min dbh) to 21% (60 cm dbh).

Bote, P.P. 1983 Financial feasibility of selective logging as a harvesting method in a virgin forest: the Taggat case. *The Philippine Lumberman* 29(10): 13-19, 35.
- Analysis of the financial feasibility of selective logging in virgin dipterocarp forests of the Philippines.

- Prescribed minimum number of healthy (uninjured) commercial residuals in 20-60 cm dbh classes is 70% and for the +70 cm class 40% (assuming based on stems in original stand).
- Supervised setting 21B8R had 71.7% (20-60 cm class) and 46.6% (+70 cm class)(7 ha).|
- Supervised setting 21C8R had 65.2% (20-60 cm class) and 40.0% (+70 cm class)(6 ha).
- Unsupervised setting 14 had 46.8% (20-60 cm class) and 23.0% (+70 cm class).
- Unsupervised setting 13 had 26.1% (20-60 cm class) and 36.4% (+70 cm class).
- It is obvious that more wood volume or more mature harvestable trees can be harvested during the first cut.
- Volume removed on 21B8R was 204.9 m^3/ha and 120.2 m^3/ha for 21C8R.
- ROI for set-up B8R was 317% and for C8R it was 258% (i.e., money yield on wood harvested vs. harvesting cost).
- Production costs and returns were similar in both supervised and unsupervised settings
- The lower damage rates were due mainly to better supervision.
- Sensitivity analysis showed that the production costs could increase 30%, 30% decrease in yield and 20% fall in the product price and still make a profit.

Boulter, D. & Darr, D. 1996 *North American timber trends study*. United Nations, UN-ECE/FAO Timber Section, Geneva, Timber and Forest Study Paper No. 9.

- In Canada the m^3 of round wood required to produce 1 m^3 of sawn wood or plywood fell from an average of 2.67 m^3 in 1970, to 2.14 m^3 in 1984, to only 1.98 m^3 in 1996.

Bowyer, J.L. 1997 Strategies for ensuring the survival of tropical forests: can logging be one of them? *Forest Products Journal* 47(2): 15-24.

- Logging often results in significant damage to the residual stand even when total deforestation is not the outcome.
- IMAZON reported findings that forest damage associated with conventional logging could be reduced by 30% through better planning or harvest operations and better training of logging crews.
- Up to 19% of the harvest volume (7 m^3/ha) was left behind after logging because skidder operators could not locate the logs.
- With reduced impact logging felling damage is minimal and soil disturbance is significantly reduced.

Brotoisworo, E. 1991 Indonesian forest resources and management policy. *In*: Howlett, D. and C. Sargent (eds.). *Proceedings of Technical Workshop to Explore Options for Global Forestry Management*, Bangkok, Thailand, April 24-30, 1991, International Institute for Environment and Development. p.254-262.

- The main (if not the only) forest management system applied is the Indonesian Selective Cutting System and more recently modified as the Indonesian Selective Cutting System and Planting System.
- Specifies a minimum dbh felling limit of 50 cm and a 35-year logging cycle.
- Inefficient logging practices have resulted in relatively high logging waste, i.e. 35-40%.
- There has been a stimulation of industries to use lesser known species and residual wood as raw materials.
- Low skill of logging workers has caused much damage in the forest in the past.
- Concession rights are only valid for 20 years, while the cutting cycle stipulated by law is 35 years. The resulting lack of interest on behalf of the concessionaires has led to over cutting and re-logging, aggravated by lack of knowledge about enrichment planting, tending residual stands.
- The Ministry of Forests has recently taken serious measures including cancellation of concession rights, and fines for non-compliance with regulations.
- New regulations to modify the Indonesian Selective Logging System specify that pre-felling inventories must be made to assess whether residual stands contain an adequate stocking of 25 at least 25 undamaged trees per hectare, of desired species of 20 cm dbh and larger, which can be harvested economically within 35 years. If this is not the case then enrichment planting has to be undertaken.

Brown, S. & Lugo, A.E. 1990 Tropical secondary forests. *Journal of Tropical Ecology* 6: 1-32.

- Rates of wood production based on short-term measurements (1-2 years) are variable and range from 2-11 t/ha/year, which are greater than in mature tropical forests of 1-8 t/ha/year.
- The factors for converting commercial volume to wood biomass = 1.1 for dry and moist forests and 0.9 for wet forests (or for biomass to volume 0.909 and 1.111, respectively).

- Forest structure and growth (all trees to a minimum 10 cm dbh) of some secondary forests.

	Commercial volume m^3/ha	**Volume increment m^3/ha/yr**	**Time period, years**
Tropical very dry forest[1]			
- fire, grazed and logged (2 entries)	31.3	0.58	15.2
	25.0	0.31	15.2
- undisturbed (average of 2 stands)	131.0	3.36	4.0
Tropical dry forests[1]			
- fire, grazed	103.2	2.07	9.8
- fire, grazed, logged (2 entries)	111.8	1.75	8.1
	137.3	1.64	6.2
- undisturbed (average of 6 stands)	208.0	4.40	17.0
Tropical montane moist forest[1]			
- logged	120.3	4.20	23.9
- undisturbed (average of 3 stands)	368.0	4.15	14-24
Tropical wet forest[2]			
Managed forest (with 8-9 native commercial species), 15 years			
- sand bank near river	507	33.8	-
- plateau	410	27.5	-

[1]Veillon, J.P. 1985. El creceimiento de algunos bosques naturales de Venezuela en relación con los parámetros del medio ambiente. Revista Forestal Venezolana 29: 5-122.
[2]Rosero, P. 1979. Some data on a secondary forest managed in Siquirres, Costa Rica. In: Kunstadter, P., E.C. Chapman and S. Sabhasri (eds.). Workshop: agroforestry systems in Latin America. CATIE, Turrialba, Costa Rica. P.209-210.

Bruenig, E. 1996 *Conservation and Management of Tropical Rainforests: An Integrated Approach to Sustainability*. CAB International, University Press, Cambridge, UK. 339pp.

- Over logging removes more than 50%, and up to 80-90%, of the canopy, completely altering the structure and function of the ecosystem.
- Cutting and smashing of the intermediate trees, which are the fastest growing part of the growing stock, and destroying a large proportion of the regeneration reduces tree increment far below the site potential.
- Wasteful harvesting and so-called volume adjustment and illegal removal cause the forest areas to be logged two to three times faster than necessary.
- More difficult is the assessment of the present value of losses of future increment and yield caused by overuse, misuse and mismanagement, and of the consequent reduction of employment and economic activity in the future.
- Low-yield logging in the more strongly successional African rainforests is, in every respect, a fundamentally different matter from high-yield logging in Malaysian MDF or Peat swamp forest.
- Selective logging in Africa has little effect on the ecological conditions of the forests that retains its resource value, assuming that a wider range of tree species will become marketable in the future.
- The conclusion is that the current system of selective logging is socially harmful and requires fundamental changes of harvesting, management and infrastructure, and the upgrading of moral attitudes and professional performance of concession owners, managers, technicians, labourers and government.
- If current conventional selective logging continues, at least in Malaysia, the supply potential would be reduced to half or one-third of the sustainable potential under a proper selection silvicultural system.
- Felled trees, not the forest, should be utilized more thoroughly. Recovery rates are badly in need of substantial improvement. The timber must be better graded at source to be sold in the most lucrative markets. At present, high-grade tropical timber is sold in low-price markets as commodity timber in competition with cheaply produced temperate and subtropical plantation and natural-forest hardwoods and softwoods.
- Planning is the most essential function to be performed in logging business (Conway 1986).
- The intensity and kind of harvesting must be fully compatible with the objectives of silvicultural stand management.
- Ideally, the residual stand must include the fast growers in the 40-80 cm diameter range and damage to the residual trees and the soil must be kept to the absolute minimum.
- In conventional selective logging with crawler tractors, loosen, move and compact the soil on 20-60% of the area .

- At the common cutting rate in MDF of 10-20% of the volume, proper selection felling with extraction by crawler tractor, damages 20-30% of the basal area of the residual stand. The damage rapidly increases with intensity of cut, at 50% removal reaching 70-80%. Beyond this, the falling crowns and skidding smash practically the whole residual stand.
- Conventional selective logging as currently practiced causes 70-80% damage with only 10-20% basal area removed.
- State-of-the-art, traditional, well-planned and skilful harvesting, more recently termed reduced impact logging (RIL), is the most promising and immediately effective strategy within forestry towards sustainability. It is cost-neutral, costs of planning and supervision being balanced by savings in operations and higher out-turns.
- RIL has a long tradition in tropical and temperate forests, the essential condition is to integrate harvesting with management planning, execution, monitoring and control.
- Essential technical features of RIL are: pre-felling survey and mapping of topography, site and growing stock, technical planning of access and extraction, including roading and drainage specifications, pre-felling climber cutting, direction felling towards planned skid trails and multiple impact zones, but away from streams, low stumps, efficient utilization of the felled trunks, minimized width of road and skidtrails, proper winching, use of an arch/fairlead/pan, no criss-crossing by tractors, slash management to reduce fire hazards and water pollution, adequate safety and working conditions, and general compliance with plans, rules and standards (these are age-old traditional principles of orderly forestry).
- The adoption of the principles of orderly harvesting makes social, economical, environmental and ecological good sense.
- In RIL at least 20-30% fewer crop trees in the 40-60 cm diameter class are destroyed or damaged, so that larger timber of high quality is produced in the next felling cycle.
- Putz and Pinard (1993) found 50% damage to the residual stand in conventional logging.
- Phillips (1993) found 43% residual stand damage in conventional logging (Sabah); on average 168 m^3 of the growing stock was damaged or killed to harvest 54 m^3/ha logs
- RIL can result in 50% less damage to the residual growing stock.
- In current selective logging 20-50% of merchantable timber goes to waste due to poor standards of felling, bucking and grading, carelessness, poor management and lack of supervision in the felling areas.
- A post-logging survey of 7 ha of selectively logged MDF and Kerangas forest (KF) in Sabal Forest Reserve (RP 146) measured 15.2 m^3/ha of merchantable log timber of good quality and sizes left behind (the amount extracted was 31 m^3/ha), which results to 33% of the merchantable felled trunks being wasted.
- The above waste could have been avoided with RIL and more timber extracted, or less area harvested.
- In conventional selective logging, no only the skid trails but also the roads are notoriously badly aligned, drainage is poor and very ineffective, and the right-of-way clearing is excessively wide (between 50 and 100 m wide).
- Tractor drivers bulldoze their way from tree to tree without planning and without considering the best extraction routes, causing particularly bad criss-crossing in easier country (Yeo 1987).
- Another study in Sarawak showed that RIL reduced damage to residuals by a third
- Replacement of the conventional practices of selective logging by RIL reduces the logging costs per m^3 extracted timber by 20-30% and the damage to the residual stand and the soil is reduced by at least 25-30%.
- It is well-established knowledge from experience in temperate and tropical forestry that well-planned and executed timber harvesting costs less than haphazard and unskilled logging. However, this fact has been frequently questioned by uninformed outsiders in discussions on sustainability. There is ample evidence that the badly planned and organized conventional selective logging by crawler tractor in the current fashion of roading and logging is more expensive with respect to direct and indirect costs than proper, sustainable selection harvesting and can be almost as expensive as helicopter logging.
- The reasons are that work performance is extremely poor and inefficient, machine wear and road maintenance are excessively costly, many of the internal costs are not even accounted for, and externalities are ignored. Lack of skills and poor management result in excessive soil movement and machine time usage in road-making and log extraction. Poor standards of drainage, road and skidtrail construction waste time and labour, and cause excessive wear of machinery. Technically poor and badly maintained equipment and unskilled labour increase machine wear, operation time and timber waste in felling, extraction and transport. The rate of work-related accidents is extremely high, but hardly appears as a cost factor.
- Many of these points also applied in the past to the conventional practice of native "kuda-kuda" logging in Peat swamp forest. Proper and orderly sustainable harvesting was introduced in the 1950's against initial

opposition by most concessionaires. The results were reduced costs, improved working conditions and safety, and increased out-turn per felled tree, improving overall private and social profit.

- Korsgaard (1985) concluded from results of field work in Sarawak, "there is no reason to tolerate harvesting operations that are wasteful and damaging."
- Marn and Jonkers (1981) study in Sarawak found RIL reduced skidding costs (-25%), skidtrail area (-22%), canopy opening (-44%), loss of commercial residuals (-33%), abandoned merchantable timber (-48%), cost per cubic meter extracted (-26%) and working time per m^3 (-25.5%), when compared to conventional selective logging.
- Putz and Pinard (1993) estimated the cost of RIL (1993 USD) as: $50/ha surveying and mapping, $10/ha for planning and marking skidtrails, $35/ha for directional felling, $40/ha for drainage of roads and skidtrails. The total additional cost was $135/ha or $1.70/$m^3$, with a logging intensity of 80 m^3/ha. However, this was the first time the crew had implemented RIL and there were extra training and learning costs included in the above.
- The above costs have to be weighted against the savings in extraction costs, increase in timber recovery and gains in productivity.
- Recent African and Amazonia studies corroborate the Malaysian experience, that sustainable harvesting is more profitable and cost-efficient than the conventional selective logging.
- Harvesting intensities of 40-60 m^3 every 25 years as visualized in Malaysia would certainly exceed the rates of replenishment of any of the nutrients.
- The tentative conclusions are that the gaps formed and the log timber extracted in selection felling (RIL) do not impoverish the nutrient stock, provided safe minimum standards per hectare are maintained: 0.1-0.3 ha gap area, 2-5 trees felled, 30-60 m^3 extracted, >40-year felling cycle.
- Selective logging with blanket application of a minimum diameter limit as low as 50-60 cm in MDF, or even less in Peat swamp forest, removes immature trees which are in the `great period of growth' with the highest current rates of basal area, volume and value increment.
- The fastest-growing trees with the highest volume and value increment in the `great period of growth' between 40/50 and 70/80 cm diameter are cut prematurely in ecologically excessive and economically unnecessary, heavy selective logging.
- In heavy selective logging, PEP declines severely to as low as 50% and less of the naturally possible volume and value increment.
- Excessive and poor roading and skidding, heavy soil erosion and compaction, and damage to immature residual trees depresses NPP and PEP still further to between 25-50%.
- Consequently in these types of situations felling cycles of 25-50 years are not sustainable and 60-100 years are more realistic (even longer on poor soils).
- The first cycle of selective logging maximizes quick and easy cash flow and profit for the concessionaire.
- Another example of indiscriminate diameter limit cutting in Sarawak mixed Peat swamp forest - initial growing stock volume 357 m^3/ha dbh >20 cm, felling intensity 28.4 trees per ha (42.4% of basal area), caused a canopy opening of 60-70%, 59.6% of residual growing stock severely damaged, 17.8% slightly damaged and only 8.2% undamaged, almost 200 m^3/ha of logging slash was left.
- In Sabah, research into logging damage, regeneration and growth after first cutting in MDF began early in the 1950's.
- Experimental comparison of tree-species richness in 20, 1 ha research plots in Liberia between primeval natural forest and modified selection-harvested forests with and without silvicultural manipulation has shown that 15-20 years after intervention no statistical differences in tree-species richness and spectra exists between them (no species losses, except for one species in one of the primeval control plots).
- The conventional simple selective logging with 50-60 cm diameter limit and too-short (15-30 years) felling cycles, and clear-felling of rainforests over large tracts remove the fast-growing and value-producing trees in the 40-80 cm diameter classes and destroy the architectural and organizational structure of the ecosystem and the PEP potential (PEP = primary economic productivity and NPP = net primary production).
- A diameter limit felling of 50 cm is better than 40 cm, and 60 cm would probably yield even better results (Peat swamp forest in Sarawak).
- The felling cycle should be between 40 and 60 years depending on the species composition and silvicultural treatments, but not less (30 m^3/ha logging intensity?).
- (Long list of references) In spite of this well documented and solid base of practical experience and guidance, dissemination of knowledge and enforcement of norms and codes of conduct fell short almost everywhere, except in Queensland and in individual concession areas of more committed companies. Forest misuse and abuse remained rampant, over logging and underutilization persisted in tropical forests and elsewhere.

Bruijnzeel, L.A. 1992 Managing tropical watersheds for production: where contradictory theory and practice co-exist. *In*: *Wise management of tropical forests*. Proceedings of the Oxford Conference on tropical forests. Oxford Forestry Institute, Oxford. p.37-76.

- Covers all residual trees are damaged in polycyclic systems, and all residual trees are damaged in monocyclic systems.

Buenaflor, V. 1989 *Logging in Papua New Guinea.* Food and Agriculture Organization of the United Nations, UNDP/FAO Project FAO:DP/PNG/84/003, Working Document No. 15. 67pp.

- A critical review of uncontrolled logging operations in PNG.
- Over 30% of most logged areas are destroyed by uncontrolled skidding.
- Over 40% of the residual trees 20-50 cm dbh are damaged by uncontrolled current logging.
- Minimum dbh for felling is 50 cm, although for export markets operators do not generally fell trees below 60 cm dbh.
- Current average extracted volume is about 30 m^3/ha, but can be as low as 15-25 m^3/ha.
- Estimates that if RIL was used the harvest level could be 60 m^3/ha after 30 years.
- Outlines the RIL technique, including post harvesting assessment.
- Extractable volume in PNG forest averages 6-15 trees/ha or 20-60 m^3/ha.
- Skid roads about 100-120 m/ha or 400-480 m^2/ha (4.0-4.8% of area).
- Vanimo case study: showed major impact due to non-compliance to the logging plan (e.g., road right-of-way widths of 25 and 18 m, when 14 m was planned; skid roads were 5 m wide when planned was 4 m; 20-30% of the area damaged).
- Wawoi-Guavi case study: the cost of 1.08 K/m^3 (K=Kina) for forest planning and engineering was offset by a skidding productivity increase from 8.42 to 12.10 m^3/MOH (44%) and a skidding cost decrease from 4.70 to 3.27 K/m^3; in uncontrolled area 67% of residuals undamaged with logging intensity of 23 m^3/ha, while 78% undamaged in controlled with logging intensity of 32 m^3/ha; area damaged was 13.7% in uncontrolled and 11.0% in controlled.

Buenaflor, V.D. 1990 *Forest management research and development, Papua New Guinea: report on improved forest harvesting*. Food and Agriculture Organization of the United Nations, UNDP/FAO Project Report FAO:DP/PNG/86/009. 36pp.

- Project deals with Manus Province.
- Assumed a 30 year cutting cycle and 0.75 cm/year diameter growth in AAC calculations, along with a 10% reduction for breakage and defects.
- Selective logging is not seriously practiced by many logging operations in the country.
- No detail plans for operations, boundary of the operational area is imaginary, no pre-laid skid road, no marking of harvestable trees or felling directions, and minimal follow-up in the field after logging.
- There is a need to change to RIL to practice selective logging to perpetuate the forest resource and to maintain the environmental stability of the area.
- Some of the trees in the 50-60 cm dbh class need to be retained as future crop trees to maintain adequate forest cover and seed trees.
- Outlines a suggested methodology to implement RIL and course field practitioners in RIL.

Buenaflor, V.D. & Heinrich, R. 1980 *FMC tracked skidder logging study in Indonesia*. Food and Agriculture Organization of the United Nations, Project FO:INS/78/054, working paper 7. 103pp.

- Tropical lowland tropical forest (with seasonal flooding) in Sumatra:
    - In logging area average volume extracted of 15.8 m^3(sob)/ha (5 trees/ha with average tree size of 3.2 m^3(sob)).
    - A bark allowance of 15% was made to obtain 12.7 m^3(sub)/ha.
    - The study block had a lower logging intensity than in the other blocks, where it averaged 21 m^3(sob)/ha or 18 m^3(sub)/ha)
- Tropical high forest in steep terrain in South Kalimantan:
    - On average 146 m^3/ha of commercial species with dbh >50 cm available, of which 120 m^3/ha are dipterocarp.
    - In study area 10.37 trees/ha (dbh >60 cm commercial species) with a volume of 147.1 m^3(sob)/ha (100% cruise of 500 ha area) was available.
    - Spur roads 6-8 m wide, and radius of clearing for log landings is up to 50 m (holds 50-60 logs at a times).
    - Skid distances average from 1000 to 2000 m.

- Average road density is 15-20 m/ha.
- In FMC areas the average skid trail density was 33.3 m/ha.
- In FMC 100 ha area 198.04 m^3/ha of which 155.11 m^3/ha extracted (78% of total volume).

Buenaflor, V. & Karunatilleke, T.D.R.W. 1992 *Harvest planning and operations study in wet zone natural forests, Sri Lanka.* Food and Agriculture Organization of the United Nations, FO:DP/SRL/89/012.

- Most of the natural forests in the wet zone have been logged a number of times and the growing stock has reached a very low level in many areas.
- At present up to 70% of the wood being logged in natural forests is wasted owing to both the methods of harvesting and utilization, and the non-availability of markets for wood.

Bullock, S.H. 1980 Impacts of logging in littoral Cameroon. *Commonwealth Forestry Review* 59: 208-209.

- Trees/ha (34 taxa, dbh>80 cm) extracted over a region of 474 km2 (range 0.1-4.0 trees/ha).
- Direct logging disturbance affected 8.4% of the area.
- +- 14.7 m of tractor trail per tree extracted.
- The mean size of gaps was 400 m2 (n=100) with damage or death to 5.2 adjacent trees >25 m tall, and 6.2 trees between 15-25 m tall.
- Less than 5% of the timber trees had lianas.
- Of 47,407 ha in region:
- Area of compacted roadbed was 386 ha (0.8% of the region).
- Area of road shoulder was 857 ha (1.8% of the region).
- Area of trails was estimated 727 ha (1.5% of the region).
- Area of tree fall gaps covered about 2001 ha (4.2% of region).

Burgess, P.F. 1971 Effect of logging on hill dipterocarp forest. *Malayan Nature Journal* 24: 231-237.

- On average 15 trees/ha felled (6 trees/acre).
- In a study of a 100 acre logging site 35% (% of basal area) of the trees were undisturbed, 55% were destroyed in the extraction process and 10% were actually extracted.
- Road making is probably the greatest damaging factor in hill forest exploitation.
- In general loggers pay little attention to drainage on their roads, and the road is usually `daylighted' to a width of one chain on either side by felling all trees and most undergrowth to enable the sun to dry out the surface.
- Poison girdling, while it is an excellent silvicultural practice when carefully controlled, does much to increase the loss of species in exploited forest and by the long-delayed effects of the falling of poisoned trees it extends the period of disturbance to the ecosystem.

Byron, N. & Perez, M.R. 1996 What future for the tropical moist forest 25 years hence? *Commonwealth Forestry Review* 75(2): 124-129.

- Virtually all pulp and paper and reconstituted panels can be derived from plantations or from heavily modified temperate forests.
- Tropical timber will increasingly change from a bulk commodity to an exclusive, high-value product for niche markets in affluent countries.
- Any interventions that reduce the commercial (or subsistence) value of TMF will undermine the economic basis for their retention, thereby accelerating conversion to agriculture.
- If logs become unsaleable for whatever reasons, they may simply be burnt if forest conversion remains profitable, to whoever is doing it, due to the economics of alternative land uses and the rewards to ‘land-claiming'.

Cannon, C.H., Part, D.R., Leighton, M. & Kartawinata, K. 1994 The structure of lowland rainforest after selective logging in West Kalimantan, Indonesia. *Forest Ecology and Management* 67(1-3): 49-68.

- Harvest removed 43% of the pre-cut basal area, and 62% of the pre-cut dipterocarp basal area (5.7 m2/ha in 6 months, 5.4 m2/ha in 1 year, 4.1 m2/ha in 8 years, mean 5.1 m2/ha)
- Residual dipterocarp trees <50 cm dbh suffered high mortality after logging, possibly limiting future wood production.
- On an average 76% of the crown cover had moderate to heavy disturbance (45% heavy disturbance to the canopy).
- In the 6 month after logging area 18.4% of the forest floor was disrupted by roads, tractor tracks and skid trails, while after 1 year it was 14.0% and after 8 years 6.2% (lower level partly due to lower logging intensity and partly to recovery after 8 years).

- The total basal area in the area 8 years after logging was still only half of that found in nearby unlogged forest.
- Clear evidence of vegetation recovery 8 years after logging, however, more than 8 years is required for severely disturbed areas to recover any canopy structure beyond the short-stature stands formed by pioneer species.

Canonizado, J.A. 1978 Simulation of selective forest management regimes. *The Malaysian Forester* 41(2): 128-142.
- Data for simulations from 45 logging set-ups representing 2023 ha.
- Intensive logging damage surveys were made on 43 of the 45 logging set-ups.
- No logging intensity data or residual stand information are given.
- Average residual damage in contractor operated areas to dipterocarps 27.8% and non-dipterocarps 38.5%; and in company operations to dipterocarps 32.8% and non-dipterocarps 34.5%.

Catinot, R. 1994 Amenager les savanes boisees Africaines. Un tel objectif semble desormais a notre portee (Managing wooded African savannas. Such a goal now appears achievable). *Bois et Forets des Tropiques* 241: 53-70.
- In Cote d'Ivoire productivity is restored 9 years after logging and protection from brush fires increased the number of new stems 2.3-2.5 fold (increase in productivity from 1-1.5 m3/ha/year to 2-3 m3/ha/year (regions 700 mm rainfall/year) and 3-3.5 m3/ha/year (regions with up to 1500 mm rainfall/year)).

Cedergren, J., Falck, J., Garcia, A., Goh, F. & Hagner, M. 1996 Impact of selective logging on silvicultural values in a mixed dipterocarp forest in Sabah. *In*: *Proceedings of Forest Operations for Sustainable Forestry, XX IUFRO, World Congress*, August 6-12, 1995. IUFRO S3.05-00 and CIFOR Publication. p.39-45.
- Study of 20 treatment plots, each 5.76 ha in size.
- 310-440 trees/ha with dbh >10 cm, of which 10-20 stems/ha had dbh >60 cm.
- Basal area was 28.3 m^2/ha of which 57% were dipterocarps.
- Minimum felling diameter in Sabah is 60 cm.
- 192 climbers/ha with diameter ranging from 2-32 cm, and dead trees accounted for 3% of stocking.
- Felling intensities exceeding 100 m^3/ha are common.
- Skid trail spacing was 60 m and were planned.
- In directional felling 39% fell within 5º of intended lay, 63% within 10º of intended lay and 78% within 20º of intended lay.
- The average felling range was 185º.
- Climber cutting had no effect on felling accuracy.

Chai, D.N.P. 1975 Enrichment planting in Sabah. *Malaysian Forester* 38(4): 271-277.
- Severe damage to the soil and the forest stand itself has resulted from the recent widespread increase in the use of heavy logging machinery.
- The total damage from logging amounts to as high as 30-50% of the total land surface.

Chai, D.N.P. & Udarbe, M.P. 1977 The effective use of current silvicultural practice in Sabah. *Malaysian Forester* 40(1): 27-35.
- The greatest menace to the advance growth is careless extraction rather than felling.
- Felling coupes selected two years in advance and climber cutting done then.
- 25 commercial trees/hectare marked for retention.

Chauvin, H. 1976 Opening up the tropical moist forest and harvesting the timber: factors conditioning methods and costs. *Unasylva* 28(112-113): 80-84.
- An essential feature in the harvesting of tropical forests: the logger must also be a public works contractor.
- Successful logging operations and a good network of trails depend essentially on a good pre-harvest survey.
- The smaller the volume logged per hectare, the more elaborate and complete must be the survey.
- Felling production is affected much more by the organization of the work and by local habits.
- Skidding operations represent from 20-40% of the cost of the wood delivered to roadside.

Chim, L.T. & On, W.F. 1973 Density, recruitment, mortality and growth of dipterocarp seedlings in virgin and logged-over forests in Sabah. *The Malaysian Forester* 36(1): 3-15.

- Mortality of seedlings occurs continuously in the regeneration pool but its rate rises after logging.
- In one study 13.7% of the original number of seedlings present before logging were still alive 3 years after logging (19350 seedlings/acre reduced to 2450 seedlings/acre).
- The majority of the mortality occurred during logging (5350 seedlings/acre 1 year after).
- There was no change in species composition of the live seedlings though.
- Retention of relics as seed-bearers in open areas is relevant for regeneration and should be enforced.
- Preferable to manage the regenerating forest than plant dipterocarps in open areas; regeneration of bare lands has been shown to be a slow process though some success may be achieved.
- Undue destruction of regenerating forests should not be allowed and the Forest Department should endeavour, as far as possible to impose rules and regulations with respect to logging damage.

Chua Kee Hui, D. 2002 Helicopter harvesting in the hill mixed dipterocarp forests of Sarawak. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- Helicopter harvesting was introduced to Sarawak in April 1993 by WTK Organisation (a local timber company).
- This system of extraction is now used by many timber operators in Sarawak because of its high production performance and its ability to extract logs from otherwise inaccessible areas with minimal damage to the surrounding forest.
- No. trees felled and extracted = 1.4 - 3.5 per ha compared with 8.7 per ha for tractor logging.
- No of trees damaged or removed per tree extracted = 1.45 - 3.13 compared with 5.49 for tractor logging. ▪ Area covered in canopy gaps = 4% - 11% compared with 15.91% for tractor logging.
- The volume of remnant and rejected logs left in the field is quite high (as compared to tractor logging) due to the selection of only good merchantable logs for lifting.
- Based on a per tree extracted basis, about 1.8 to 2.3 m3 of unutilized timber are left behind in an area harvested by helicopters compared to 0.08 m3 for tractor based harvesting.
- High capital and operating costs of the helicopter.
- Higher contract rates for felling crews.
- Helicopter harvesting cots twice as much as conventional tractor harvesting.

Chua Kee Hui, D. 1996 Helicopter Logging Lifts Off in Sarawak*. ITTO, Tropical Forest Update* 6(3).

- The WTK Organization was the first company to implement helicopter logging in Sarawak in 1993.
- Helicopter logging in usually applied to areas inaccessible to more conventional extraction methods.
- Average volume per turn 5 - 7.5 m3; average turn time 3-4 minutes; average volume per effective working day 600-700 m3.
- Helicopter logging caused considerably less damage to soil and residual forest than tractor logging.
- Number of trees damaged or removed per tree extracted was 1.4-3.1 for helicopter logging compared to 5.5 for tractor logging.
- Open space created by canopy openings and skid trails as a percentage of logging area was between 4-11 for helicopter logging vs. 15.9 for tractor logging.
- Helicopter logging is more expensive per unit volume than conventional logging.

CIFOR. 1998 *Annual Report.* Centre for International Forestry Research.

- The implementation of reduced impact logging techniques can reduce impacts to the soil from heavy logging machinery by 25%, and lead to a gain of as much as 50% in the "carbon storehouse" benefits from the remaining vegetation.
- In some RIL experiments in lowland tropical forests the damage to the soil and to advanced regeneration was reduced by 50% relative to conventional logging.

Cordero, W. & Howard, A. 1996 Use of oxen in logging operations in rural areas of Costa Rica. *In*: *Proceedings of Forest Operations for Sustainable Forestry, XX IUFRO, World Congress*, August 6-12, 1995. IUFRO S3.05-00 and CIFOR Publication. p.5-12.

- Logging intensity was 6 trees/ha in oxen logged area and 7.33 trees/ha in tractor logged area.
- In oxen logged area logging effect (based on number of stems) was 1.3% extracted, 11.85% very severe injury or killed, 3.25% severe, 12.36% minor injury, 68.5% had no injury, and non-logging damage was 2.75%.

- In tractor logged area logging effect was 4.82% extracted, 19.15% very severe injury or killed, 0.86% severe injury, 14.06% minor injury, 60.66% had no injury, and non-logging damage was 5.26%.

Costa, **F. & Magnusson, W.** 2001 Selective Logging effects on abundance, diversity, and composition of tropical understorey herbs. *Ecological Applications*: 12 (3): 807 – 819.

- Little is known about the impacts on selective logging herbaceous plants of tropical forests. If logging impacts on non-timber species are low and little time is required for recovery, logged forests could be compatible with conservation of some elements of the understory flora.
- As many non-timber species may have commercial value, knowledge about the impacts of different logging intensities is necessary to determine levels of timber extraction compatible with multiple use of forests.
- In this study, the effects of logging intensity, time after logging, and skidder tracks, on the composition and diversity of the ground-level herb community of a terra-firme forest in central Amazonia are examined.
- Logging was carried out at varying intensities in eight 4-ha experimental plots in 1987, three plots in 1993, and five plots were controls. Herb community composition analysed with hybrid multidimensional scaling (HMDS), was not significantly affected by logging intensity, but was significantly related to the area covered by logging gaps and skidder tracks.
- There was no significant difference in community composition and richness between treatments with different times after logging. Species richness was also not related to the logging intensity. Some species (18.2%) were found only in logged plots and were mainly from habitats outside the rain forest.
- There were significant differences in herb composition between controls and skidder tracks, but recent and old skidder tracks were mixed in the ordination space, suggesting that recovery in skidder tracks is slower than in other areas affected by logging.
- Overall, the results indicate that the herb ground community is not severely affected by selective logging at the intensities used in this experiment. The alterations in composition are mainly local, and restricted to the most disturbed patches.
- Main conclusion: forests managed with logging intensities similar to those used in this experiment could be compatible with conservation of understory herbs. Skidder tracks should be minimised, as they have the greatest long-term impact and allow species from other habitats to invade the forest.

Crome, F.H.J., Moore, L.A. & Richards, G.C. 1992 A study of logging damage in upland rainforest in north Queensland. *Forest Ecology and Management* 49(1-2): 1-29.

- Queensland Selective Logging System studied.
- Mean removal was 6.6 stems/ha, 4.9 m^2/ha basal area and 37 m^3/ha logs.
- 146.7 stems/ha were killed during the logging amounting to 12 m^2/ha of basal area.
- Machine trails occupied 5% of the area.
- Damage was less than in other studies done in S.E. Asia.
- Could have used more of the fibre in the crowns (large branches).
- Most important to further reduce damage is to enhance the skills, sensibilities and cooperation of field personnel.
- Harvesting rainforest under a management system is now being recognized as ecologically, economically and socially preferable to its conversion to plantations and agriculture, particularly when the who range of values of the forest is considered.
- Management systems that were being abandoned in many countries are again being promoted.
- There are about 1 million ha of tropical rainforest in Queensland, between Cooktown and Townsville.
- 3-years before logging the area was surveyed and mapped and complete tree species lists produced.
- All felled trees were located on a map, identified and measured immediately after felling.
- Standing damaged trees likely to survive were not enumerated.
- 121 marked trees and 5 salvage trees of 25 species were harvested.
- Ridge sites had 23.3% of their total stems and 25% of their total basal areas removed of which 57.6% was on harvested trees.
- Gully sites lost 16.6% of total stems and 17.1% of total basal area yet only 42.4% of this total basal area loss was on harvested trees - greater `incidental losses' in gullies due to tree crowns falling from further up the slope.
- Logging did not result in the loss of any tree species from the sample sites nor was there any change in the total plant species list after logging.
- Of the 19 ha plot harvested, 3.7 ha of canopy (19.5%) was lost.
- There were 1600 m of major logging tracks, averaging 5 m in width (0.8 ha) from which all vegetation was cleared and with mineral soil exposed along their entire length = 4.2% of area.

- An additional 530 m of minor tracks averaging 3 m wide (0.16 ha) were made by the skidder (little exposed mineral soil and many seedlings and small saplings remained) = 0.8% of area.
- 18 months after logging casual observations indicated that there was little regeneration on the major logging tracks.
- After log hauling was finished the QFS constructed drains across the tracks and prohibited vehicle access - observations indicated that this, and the banning of heavy machinery in wet conditions, were effective in reducing erosion.
- The most significant factor in siltation of the stream, however, was constant erosion from the busy main access roadside alongside the study area.
- Data from various logging studies for comparison with data from the logging area on the Windsor Tableland, north Queensland:

(note variable methodologies used in studies so data is not totally comparable between studies and incidental losses include both extracted and damaged trees)

Place	Area (ha)	Harvested (/ha)			Incidental Losses (% BA)		% canopy loss	Area (%)		Study
		Stems	m^3	m^2	Killed	Damaged		All Roads	Minor Roads[1]	
Queensland	5.6	26.0	66.0	15.4	16.0[2]		18.2	26.0	4.3	Nicholson et al. (1983)[3]
Queensland	1.6	32.7	36.6	24.8	29.9		19.4		4.8	Nicholson et al. (1988)
Queensland	0.1	39.5	42.1	7.3	21.3		22.3			Nicholson et al. (1988)
Queensland	0.4	18.9		11.4	16.0					Nicholson et al. (1988)
Queensland	0.6	25.6		8.4	29.4					Nicholson et al. (1988)
Queensland	0.3	18.2		9.0	28.9					Nicholson et al. (1988)
Queensland	0.2	19.8		4.8	35.8					Nicholson et al. (1988)
Queensland	19.0	6.6		5.6	18.1					This study
Queensland	16.5	7.6			20.4					This study
Sabah	43.7	11.6	47.2		58.0[4]	45			14.0	Nicholson (1979) p.19
Sabah	8.1	15.3			40.0[4]					Nicholson (1979) p.19
Sabah	8.1	16.6			51.0[4]					Nicholson (1979) p.19
Sabah	4.0	19.0			43.0[4]					Nicholson (1979) Table19
Sabah	4.0	9.1			47.0[4]					Nicholson (1979) Table19
Sabah	4.0	12.8			29.8[4]					Nicholson (1979) Table19
Sabah	4.0	11.9								Nicholson (1979) Table19
Sabah	4.0	16.1								Nicholson (1979) Table19
Sabah	43.7	11.6								Nicholson (1958)
W.Malaysia	21.3	13.7	41.6	24.0	47.6	53.6		9.0		Nicholson (1979) Table 21
W.Malaysia		8.4								Nicholson (1979) Table 21
W.Malaysia		12.3								Nicholson (1979) Table 21
W.Malaysia		10.8								Nicholson (1979) Table 21
W.Malaysia		9.6								Nicholson (1979) Table 21
W.Malaysia		9.9								Nicholson (1979) Table 21
W.Malaysia		18.3								Wyatt-Smith et al. (1962)
W.Malaysia										Johns (1988)
Kalimantan	2.0	11.0	244					12.0	30.0	Abdulhadi et al. (1981)
Philippines	10.0	24.6	222							Nicholson (1979) Table 26
Philippines	22.2	19.8	187							Nicholson (1979) Table 26
Philippines	7.6	20.5								Nicholson (1979) Table 27
Philippines	7.6	7.2								Nicholson (1979) p.29
Amazonia	6.8	8.0	52		11.0	28.0	46.3	8.0	4.0	Uhl and Vieira (1989)
Amazonia	52.0	4.3	31							Uhl and Vieira (1989)

[1]Roads too small to allow logging trucks
[2]Stems over 20 cm
[3]Virgin plots on granite only
[4]Commercial stems only

- Average volume logged throughout the Windsor Tableland was 50 m^3/ha and some areas logged before 1982 yielded as much as 66 m^3/ha.
- Other Queensland studies would have had strict control over the timber cuttings and bulldozer drivers at all times, also machinery would have been smaller and more winching done.
- 18 months after logging casual observations showed that there was a dense growth of Stinging Tree and rattans in large gaps.
- There could be more use of the felled trees. Much timber was left in heads and large limbs and this could have been harvested with no increased incidental damage.

- In the past when smaller machines were used, winching over long distances was commonplace. Also had a helper to pull out the cable and guide the logs around residuals. Now the tractor driver has to do all this himself.
- In spite of close supervision by QFS personnel the rules were not always obeyed and the decisions of the company staff and/or contractors resulted in incorrect placement of the loading area, increased roading, increased incidental losses and stream siltation.
- This indicates how important the skills and attitudes of field personnel are and, above all, how willing they are to obey the strictures in the logging plans.
- The field operators have the power to exacerbate or ameliorate the environmental damage caused by logging and their management determines the success or otherwise of management plans.

Dagang, A.A., Richter, F., Hahn-Schilling, B. & Manggil, P. 2002 Financial and economic analyses of conventional and reduced impact harvesting systems in Sarawak. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- The FOMISS - Sampling Pilot Area (FSPA) a is located in the Upper Baram of northeast Sarawak, covering 169 000 ha.
- Comparative financial and economic analyses of CL and RIL with tractors for the FSPA was carried out.
- The financial costs and benefits of CL were analysed over two different time frames: (a) after one-year of harvesting and (b) after a 40-year rotation period in a logged-over forest.
- The project established 13 RIL trial blocks in the FSPA.
- Additional data were obtained from RIL trials in the Model Forest Management Area (MFMA) in Sibu.
- Fifty percent of the FSPA comprises primary forests with an average commercial volume of 303 m3/ha.
- The average stocking of logged-over forests averages 170 m3/ha.
- The costs of harvesting and royalties per m3 are approximately 23% higher under RIL relative to CL for the 1-year period.
- If the introductory costs for training and damage assessment are excluded, the difference is reduced to 14%.
- The profit was estimated at RM29/m3 and RM45/m3 under CL and RIL, respectively.
- If the introductory costs are excluded the profit increases to RM52/m3.
- The profit is reduced to RM20/m3 if the concessionaire does not obtain a certification premium.
- The profit per ha of the net production area totals RM1176 for CL and RM883 for RIL.
- CL was slightly more profitable and exceeds the NPV of RIL by a factor of 1.3 after 40 years.
- The BCR for RIL exceeds that of CL by a factor of 1.1.
- This means that RIL is more robust with regard to cost increases.
- In terms of the financial cash flow, the first harvest was more profitable under CL than under RIL, whereas the financial benefits of the second harvest were higher under RIL.
- The economic analysis showed that the RIL system provided a higher level of overall benefits as opposed to CL after the 40 year period.

Dawkins, H.C. 1958 *The management of tropical high forest, with special reference to Uganda*. Imperial Forestry Institute, Oxford, U.K., IFI Paper 34. 155pp.

- Area of damage associated with the removal of one tree of 70 cm dbh is not likely to be less than 200 m^2 (tree with 8 foot girth (78 cm dbh) will irreparably damage at least 0.05 acre ($202m^2$) of pole and adolescent stock).
- Classes the Queensland system as complicated to illustrate as a scheme, being based on a polycyclic system of management and supported by exceptionally skilled field staff.
- In one study the mean felling damage per tree was 0.1 ac (405 m^2), and could have been reduced to one-half of this through directional felling.
- If basal area is >140 ft^2/ac trees of THF are incapable of satisfactory growth.
- Basal area should be between 80 to 120 ft^2/ac to attain one foot girth growth per ten years.
- Presents a calculation of the impact of felling 10 trees/acre of 8 ft girth on a 40-year cycle (i.e., MAI 30 ft^3/acre/year = 2.1 m^3/ha/year), and shows that crown damage to pole size timber is so high that this yield is just achievable with careful directional felling (i.e., with careful felling gap opening of 0.05 acres/tree felled = 0.5 acres impacted).
- Any polycyclic system aiming at a MAI of greater than 2.1 m^3/ha/year will be difficult as it is bound to require more intense and more frequent felling than every 40 years.
- Partly because of the above reasoning the uniform system is recommended.

DeBonis, J. 1986 Harvesting tropical forests in Ecuador. *Journal of Forestry* 84(4): 43-46.
- Extraction is performed with ground-skidding equipment; the most common being large rubber-tired skidders.
- Report describes a conventional unplanned and uncontrolled logging operation in the tropics.
- Due to the haphazard nature of the operations 40% or more of the ground surface area is disturbed.
- In wet soil conditions bulldozers dig out trails to mineral soil to a depth of 0.25-0.5 m.
- On slopes of over 10% trails are dug out even deeper in the hope of better traction.
- The amount and intensity of damage is amplified during wet-weather skidding, where up to 75% of the area can end up covered by skid trails (trails are used until they become troughs of mud 1 m or more in depth, incapable of being reclaimed.
- When operating during the wet period, one company experienced a 100% increase in machine maintenance and repair costs, while productivity decreased to as low as 15% of average dry season productivity.
- Preplanning skid trails and directional felling could reduce the area covered by skid trails to 15%.
- By restricting skidders to skid trails and requiring more winching the disturbed area could be reduced to as low as 4%, depending on skid trail spacing.
- Sawyers receive no training in felling or bucking and their is considerable wastage due to poor trimming (i.e., log lengths not measured) and felling (e.g., no hinge to control felling direction).
- With the use of proper felling and bucking technique at least a 15-30% increase in wood volume at the mill could be realized.
- Safety is more or less disregarded (e.g., no safety equipment (many workers work in shorts with no hard hat, shirt or footwear), trees felled into areas where other workers working, no communication between skidders and sawyers so trees are pushed into areas the sawyers are working).
- Sawyers appear unaware of the need for preparing escape routes prior to felling a tree.
- A system of controls and rewards could be applied to logging contractors, including rewards for good utilization practices or fines for poor practices.
- Use of chokers could increase skidder productivity; more often than not only one log is skidded at a time, with two logs being the maximum.
- A major shift by the public sector toward enactment and enforcement of new, stricter environmental controls appears unlikely in the near future.
- Improvement of logging practices will occur most rapidly if initiated by the private sector
- If only advanced planning of skid trails and wet-weather shutdown were implemented, most of the current skidding damage could be eliminated.
- Increased productivity and reduced maintenance and repair costs to equipment would cover the above costs, as well as inventory holding costs for the approximate five months of shutdown time required.

De Graaf, N., Filius, A. & Huesa Santos, A. 2003 Financial analysis of sustained forest management for timber: Perspectives for application of the CELOS management system in Brazilian Amazonia. *Forest Ecology and Management* 177: 287 – 299.
- Sustained management of the Terra Firme Forest in Amazonia is financially analysed for an integrated forest management and timber processing industry.
- Two scenarios are studied, one with reduced impact logging (RIL) and sparing of reserves without silvicultural follow-up in a 100-year cycle option needing four times as much land as the 25-year cycle option.
- A cash flow analysis over the 100-year period for both options with a 8% discount rate shows that the total costs on the land-intensive option (25 years) with silviculture are considerably less than in the land-extensive option; the lower cost of infrastructure, log transportation and land acquisition offset the cost of silviculture. Because the annual revenues from timber sale are the same in both options, the NPV of the intensive option is also much higher.
- A sensitivity analysis shows that the land-intensive option is expected to give still a positive NPV in less favourable situations. The relatively small forest area in the land-intensive option together with the organisational setting, which includes integration with the processing industry, favours a sustainable development.
- More intensive management gives signals to settlers that helps prevent their encroachment. In addition, the higher annual increment in this option facilitates a contribution to regional development and makes a larger area available for strict nature reserves.

de Graaf, N.R. 2000 Reduced impact logging as part of the domestication of neotropical rainforest. *International Forestry Review* 2(1): 40-44.

- Applying RIL for production of marketable timber without any further steering of forest development will probably result in a steady decrease in standing volumes of timber of marketable species.
- Under the CELOS Silvicultural System a felling cycle of 20-30 years is applied to previously exploited neotropical rainforest. The forest should have been exploited under the CELOS Harvesting system, which can be classified as a reduced impact logging system.
- The maximum harvesting intensity is 30 m^3/ha. Following the harvest valuable trees have to be released with three consecutive thinnings.
- The cost per $m^3$of standing round wood produced is in the order of half a man-day.
- In Brazil (Amazonas Region) the CELOS results were applied to an area of 80,000 ha. Soils were very poor kaolinitic clays. Drainage under undisturbed forest was reasonable, but the soil was compacted easily.
- The total basal area was 30 m^2/ha. The maximum harvesting level was set to 30 m^3/ha on a 25 year cutting cycle.
- Harvesting activities were concentrated on trees with a dbh preferably larger than 60cm.
- It is estimated that about 5% of the area is compacted by machines, mostly as permanent infrastructure (skidding trails, log landings, truck roads).
- Because of the extreme nutrient poverty of the soil the extraction has to be restricted to timber logs in order to minimise nutrient exports.
- Where forest management proceeds towards classical selection felling in succeeding cycles, the frequency of harvesting may be increased to 10 or even 5 years, with a correspondingly low volume taken per ha. The reason is that an annual mortality of 2% eliminates too much potentially utilisable timber over 20-30 year long cycles.

de Graaf, N.R., Poels, R.L.H. & van Rompaey, R.S.A.R. 1999 Effect of silvicultural treatment on growth and mortality of rainforest in Surinam over long periods. *Forest Ecology and Management* 124: 123-135

- These silvicultural experiments were carried out in Surinam over a period of 30 years.
- With an initial thinning of non-commercial species from 20 to 6-10 m2 of basal area, the large-scale field trial had grown enough volume for a harvest of 20-30 m3/ha after 20 years.
- Harvesting of a considerable volume per hectare might have a similar effect of release as removing competitors around potential crop trees.
- Intensive harvesting is usually more destructive for the residual stand per unit of basal area removed than a silvicultural treatment in which trees area killed standing by means of girdling.
- The results indicate that in lightly exploited forest, the optimum schedule might be to refine or liberate heavily three times during a cycle of 20-25 years.

De Vletter, J. & Mussong, M. 1995 Natural Forest Management Project: Ein Ansatz zur nachhaltigen Bewirtschaftung von kommunalen tropischen Regenwaeldern in Fidschi. *Forstarchiv* 66: 95-100.

- The purpose of this study was to test the implementation of a silvicultural model for the sustainable management of communally owned tropical rainforest on the Fiji islands.
- The harvesting intensity for reduced impact logging was 38.7% of the initial volume. With conventional logging 81.6% of the volume were harvested.
- It was found that the local forest owners were capable of applying the prescribed management and harvesting activities. The selection of trees to be harvested was mainly based on silvicultural and ecological criteria but also included aspects of timber recovery and economics.

d'Oliveira, M.V.N. & Braz, E.M. 1995 Reduction of damage to tropical moist forest through planned harvesting. *Commonwealth Forestry Review* 74(3): 208-210.

- RIL study (previous survey, planning, climber cutting, directional felling, careful construction of skid trails and roads).
- Logging intensity is claimed to be 20 m^3/ha in Brazil, contracting the data shown in Table 1, which indicates intensity of 10 m^3/ha.
- In RIL the number of damaged trees (>10 cm dbh) per tree logged was 5.3 (or 0.27 m^3 per m^3 extracted) or 27%.
- Maximum canopy opening was 15% (including all damage to the canopy in felling, skid trail, road and landing construction).
- In a study of conventional logging by Uhl and Viera (1991), damage amounted to 1.9 m^3 per m^3 extracted, while the canopy opening was 3800 m^2/ha vs. 1500 m^2/ha in this study.

- Uhl and Viera (1991) got 13.8% canopy opening in careful logging.
- 450 m of road (5 m wide) was built (22.5 m/ha), 1200 m of skid trail was built (60 m/ha), and a landing of 225 m^2 (25 m x 35 m) was built.
- Average growing stock (dbh >10 cm) was 247.9 m^3/ha, or 133.9 m^3/ha when dbh >50cm.
- Marketable species volume was contained in 109 trees/ha, of which 19 were of commercial size.
- In the 20 ha - 57 trees were felled (2.85 trees/ha) with a total volume of 199.331 m^3 (3.5 m^3/tree or 10 m^3/ha).
- In many parts of the tropics, forest management has paid little attention to the minimization of damage caused to the forest through exploitation. The main concern has been with the choice and performance of the logging technologies and equipment employed.
- When the subject of sustaining wood production over a number of cutting cycles is considered, it becomes obvious that planned exploitation is the key to ensuring that the growing stock is maintained at a desirable level.
- In addition to sustaining timber production, it is important for the provision of other services such as biodiversity, local climate, etc.
- Regeneration also requires that attention be paid to the size of clearing, a factor much influenced by the felling operation (Yared and de Souza 1993).
- Planned production reflects positively on management costs (Hendrison 1989) - he reported that average annual skidder production doubled with planned harvesting, when compared to conventional harvesting.

DOSSIER: Recherches sylvicoles en Indonésie. 1999 STREK, CIRAD-Forêt et FORDA. *Bois et Forêts des Tropiques* #259 (1). 5-45.
- This study was carried out in Indonesia (east Kalimantan) as part of the STREK project.
- In this publication the application of silvicultural treatments and reduced impact harvesting techniques were evaluated.
- In conventional logging the minimal harvesting diameter was 60cm dbh.
- In RIL operations the minimum harvesting diameters was 50cm and 60cm dbh respectively.
- The following data were found for the correlation between damage level and mortality:

Damage level	Basal area remaining	Mortality rate (%/year)
Light	> 80%	1.6
Moderate	70-80%	2.4
High	< 70%	2.9

- 26% of residual stand were damaged during harvesting, resulting in 51% of the total mortality two years after harvesting.
- The following data show the relation between silvicultural system, mortality and growth rate:

Treatment	Mortality (m^3/ha/yr)	Growth rate (m^3/ha/yr)	Recruitment (m^3/ha/yr)	Mean annual increment (m^3/ha/yr)
Virgin Forest	1.31	2.31	0.58	+1.58
Systematic Thinning	1.32	4.85	1.37	+4.9
Selective Thinning	2.08	4.56	0.63	+3.11
Control CL	2.62	3.36	0.17	+0.91
RIL 50	2.15	3.44	0.34	+1.67
RIL 60	3.09	3.74	0.24	+0.88
CL 60	3.55	3.67	0.63	+0.75

Durrieu de Madron, L. & Forni, E. 1997 Aménagement forestier dans l'est du Cameroun. CIRAD-Forêt. *Bois et Forêts des Tropiques*. 254 (4). 39-50.
- The project API (aménagement pilote intégré) was carried out at Dimako, Cameroon.
- Harvesting intensities greater than 1tree/ha were recommended.
- A cutting cycle of 30 years and a planting prescription for areas with poor regeneration were recommended.

Durrieu de Madron, L., Fontez, B., & Dipapoundji, B. 2000 Dégâts d'exploitation et de débardage en fonction de l'intensité d'exploitation en forêt dense humide d'Afrique centrale. CIRAD-Forêt, Projet ECOFAC. *Bois et Forêts des Tropiques*. 264 (2). 57-60.
- This study was carried out in Central Africa.

- The main objective of the "ECOFAC" project was to determine the relation between harvesting intensity and damage to the residual stand.
- Most of the damage was caused during skidding operations.
- The harvesting intensity ranged from 0.4 - 4 trees/ha.
- The minimum harvesting diameter was 80cm dbh, however, few trees smaller than 90cm dbh were cut.
- The following data were found for the relation of site damage and harvesting intensity:

Harvesting Intensity (trees/ha)	Site Damage (% of total area)
0.24	3.71
0.44	3.79
0.60	7.21
0.76	4.35
0.88	6.11
1.16	9.40
1.20	9.05
1.28	7.90
1.40	9.17
1.68	12.40
1.76	14.60
1.84	10.95
2.32	15.68
3.28	19.90

- On average 0.8% of the surface were affected by roads and landings.

Durrieu de Madron, L., Forni, E., & Mekok, M. 1998 Les techniques d'exploitation `a faible impact en forêt dense humide camerounaise. CIRAD-Forêt. 1998. 29pp.
- This publication is based on results from Project A.P.I. de Dimako (east Cameroon) and studies from the Ivory Coast and Central Africa.
- The main goal of this study was to identify harvesting techniques that minimise damage to the residual stand.
- Maximal harvesting intensity (A.P.I. de Dimako) was increased from 0.8 trees/ha (10 m^3/ha) to 3 trees/ha (40 m^3/ha).
- A sufficient number of seed trees must be retained to provide for regeneration and biodiversity.
- Approximately 25% of the harvested volume was left behind as waste or due to oversight.
- Main and secondary roads affect 1-2% of the total area.
- With harvesting intensities of 0,5-1 tree/ha (5-15 m^3/ha) approximately 3% of the site is damaged during skidding operations.
- Governments should provide economic incentives for the implementation of reduced impact logging techniques.

Durst, P.B. & Enters, T. 2001 *Illegal logging and the adoption of reduced impact logging*. Paper presented at the Forest Law Enforcement and Governance: East Asia Regional Ministerial Conference, Denpasar, Indonesia.
- Effective RIL programs include elements of monitoring, auditing, and enforcement of rules, laws, regulations and guidelines.
- There are a number of linkages between RIL and other necessary conditions for sustainable forest management.
- The links only become apparent when examining the impediments to the adoption of RIL and in particular the effects that illegal logging has on profitability and decision making by forest concessionaires.

Dykstra, D. 2003 *RILSIM: A financial Simulation Modelling System for Reduced-Impact Logging*. Paper presented at the Second International Forest Engineering Conference; Vaxjo, Sweden.
- RILSIM is a computer software package designed to permit users to rapidly estimate the cost and net revenue associated with logging operations so that they can compare short-term financial costs and returns expected from reduced impact logging with those expected from conventional logging under identical local site conditions.

- The purpose of the software is to help users learn about reduced-impact logging and its potential financial advantages as compared to conventional logging.
- The focus of efforts to introduce RILSIM is on users in tropical countries where logging impacts are widely considered to be incompatible with sustainable forest management.

Dykstra, D. 2002 Reduced Impact Logging: concept and issues. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- RIL involves the application of technologies that have been known for many years and are utilized as a matter of common practice in many industrialized countries.
- RIL requires both a new mindset and also a new approach to tropical forest management.

Dykstra, D. 2001 The old and new of reduced impact logging. *ITTO Tropical Forest Update* 11(2): 3 – 4.
- RIL has become associated with logging technologies that have been introduced into tropical forests explicitly for the purpose of reducing the environmental and social impacts associated with industrial timber harvesting.
- This paper discusses the requirements for RIL and some of the impediments to its implementation in the tropics.

Dykstra, D., Toupin, R. & Othman, M. 2001 *Steps toward sustainable forest management in Central Africa. Report of an exploratory visit to timber concessions in the Republic of Congo and Gabon*. CARPE/USAID.
- Field report of visit to two timber concessions in central Africa: CIB (Société Congolaise Industielle des Bois) and SBL (Société des Bois de Lastoursville).
- Both CIB and SBL are at an early stage in the process of developing comprehensive forest management plans for their timber concessions.
- Inventories will be carried out on a 1% sampling basis by both companies. Regeneration surveys will be done at a lower sampling rate. This information will be combined with physical information on roads, streams, topography, and other features to develop both operational and long-term management plans.
- Efforts by both CIB and SBL to control hunting and bush meat trade appear to be having a positive effect as officials of both companies report an increase in the availability of beef and poultry in local markets where previously bush meat was the primary source of protein.
- Conversion ratios for both companies' sawmills average around 30%.

Dykstra, D. 1992 *Wood residues from timber harvesting and primary processing: a global assessment for tropical forests*. Food and Agriculture Organization of the United Nations, unpublished mimeograph. 93pp.
- Estimated volume of trees left standing on harvested areas, forest residues, and felling recovery rates for the three tropical regions around 1986, with data for the U.S.A. provided for comparison sake:

Region	Estimated standing volume on harvested areas (mill.m^3)	Estimated residual volume on harvested areas (mill.m^3)	Estimated volume felled (mill.m^3)	Estimated forest residues (mill.m^3)	Industrial round wood production (mill.m^3)	Estimated felling recover rate (%)
Africa	251.664	179.587	72.077	33.512	38.565	54
Asia/Pacific	905.822	669.672	236.150	127.884	108.266	46
Latin America/ Caribbean	657.273	499.556	157.716	70.014	87.702	56
Total	1 814.759	1 348.815	465.943	231.410	234.533	50
U.S.A.	na	na	493.385	110.796	382.589	78

- Estimated sawmill recovery rates for the tree tropical regions around 1986, with data for the U.S.A. provided for comparison:

Region	Sawn wood production (mill.m^3)	Estimated sawmill residues (mill.m^3)	Estimated sawmill recovery rate (%)
Africa	6.503	7.527	46
Asia/Pacific	34.314	34.027	50
Latin America/ Caribbean	25.424	34.415	42
Total	66.241	75.969	47
U.S.A.	88.065	122.667	42

- Estimated plywood recovery rates for the tree tropical regions around 1986, with data for the U.S.A. provided for comparison:

Region	**Plywood production (mill.m^3)**	**Estimated plywood residues (mill.m^3)**	**Estimated plywood recovery rate (%)**
Africa	0.445	0.455	49
Asia/Pacific	7.969	8.741	48
Latin America/ Caribbean	1.433	1.801	44
Total	9.847	10.997	47
U.S.A.	22.710	24.522	48

- Amount of logging and mill residues generated in the tropics was estimated to be 208 million m3 annual, or 89% of the total annual production of industrial round wood.
- About 60% of mill residues in tropical countries are unutilized.
- Report has logging residues, sawmill and veneer mill residues for Cameroon, Ghana, Nigeria, Indonesia, Malaysia, Philippines, Thailand, Brazil, Columbia and Peru.

- Quantities and types of residues generated at each stage of the harvesting operation (10 country average) (all volumes 1000 m^3 sob):

Total m^3 of standing timber on logged areas (TVOL) = 42150.2	
	Volume of non-utilized species = 6884.5 (16.3% of TVOL)
	Volume of small-dimension trees = 1805.0 (4.3% of TVOL)
	Volume of reserved commercial trees = 4518.5 (10.7% of TVOL)
Volume to be felled (VFELL) = 28942.2	
	Volume in high stumps = 1918.9 (6.6% of VFELL)
	Felling breakage = 1226.2 (4.2% of VFELL)
Volume to be limbed and crosscut (VL&C) = 25797.1	
	Rejected pieces = 8454.3 (32.8% of VL&C)
	Losses due to improper bucking = 361.2 (1.4% of VL&C)
Volume to be skidded (VSKID) = 16981.7	
	Skidding breakage = 263.0 (1.5% of VSKID)
	Lost or rejected pieces = 413.2 (2.4% of VSKID)
Volume at landing (VLAND) = 16305.4	
	Loading losses and damage = 853.3 (5.2% of VLAND)
Volume on truck (VTRUCK) = 15452.1	
	Transport losses and damage = 124.9 (0.8% of VTRUCK)
Industrial Round wood Volume = 15327.2 (36% of TVOL or 53% of VFELL)	Should approximately equal IRW production as reported in the FAO Yearbook of Forest Products

• Quantities and types of residues generated during sawn wood production (10 country average):

Volume scheduled for harvest (TVOL) = 42150.2	
	Timber not harvested = 13208.0 (31.3% of TVOL)
	Harvesting and transport losses = 13615.0 (32.3% of TVOL)
Industrial round wood volume (IRW) = 15327.2	
	Volume to other mills or export = 6715.2 (43.8% of IRW)
Volume at sawmills (VSMILL) = 8612.1	
	Debarker residues = 140.4 (1.6% of VSMILL)
	Sawdust = 767.9 (8.9% of VSMILL)
	Slabs and edgings = 1994.9 (23.2% of VSMILL)
	Board end trimmings = 403.5 (4.7% of VSMILL)
	Planer shavings = ---
	Drying losses = ---
	Unusable sawn wood = ---
	Other conversion losses = 1450.8 (16.8% of VSMILL)
Volume of sawn wood production (VSAWN) = 3854.7 (44.8% of VSMILL)	
	Storage and transport losses = 56.3 (1.5% of VSAWN)
Sawn wood delivered to market (VSDELIV) = 3798.4	
	Premature degradation = ---
Sawn wood in final use (VSFINAL) =3798.4	

- Quantities and types of residues generated during plywood processing (10 country average):

Volume scheduled for harvest (TVOL) = 42150.2	
	Timber not harvested = 13208.0 (31.3% of TVOL)
	Harvesting and transport losses = 13615.0 (32.3% of TVOL)
Industrial round wood volume (IRW) = 15327.2	
	Volume to other mills or export = 13612.7 (88.9% of IRW)
Volume at plywood mills (VPMILL) = 1705.5	
	Debarker residues = 58.8 (3.5% of VPMILL)
	Cores and lathe roundup = 197.1 (11.6% of VPMILL)
	Spur knife trim = 19.3 (1.1% of VPMILL)
	Veneer waste and clippings = 227.4 (13.3% of VPMILL)
	Drying losses = 19.4 (1.1% of VPMILL)
	Panel trimmings = 34.3 (2.0% of VPMILL)
	Sander dust = 12.1 (0.7% of VPMILL)
	Volume replaced in patching = --
	Other conversion losses = 301.2 (17.7% of VPMILL)
Volume of plywood produced (VPLY) = 835.9 (49.0% of VPMILL)	
	Storage and transport loss = ---
Plywood delivered to market (VPDELIV) = 835.9	
	Premature degradation = ---
Plywood in final use = 835.9	

- Harvesting operations in natural tropical forests can reduce logging residues by 10-30% without a significant increase in harvesting cost.

Dykstra, D.P. & Heinrich, R. 1992 Sustaining tropical forests through environmentally sound harvesting practices. *Unasylva* 43(169): 9-15.
- If tropical forests are to be retained as forest, then for the most part their resources must be utilized. Otherwise, they risk being perceived by local people and government decision-makers as having less value than other land-use options.
- Improper harvesting practices can so degrade the forest that future timber and non-timber values may be substantially reduced.
- There is evidence that the degree of damage is increasing as logging operations extend over more rugged terrain and become increasingly mechanized, relying to a greater extent on "horsepower" rather than on technical competence (Fox 1968, Nicholson 1979, Marn and Jonkers 1982).
- Sufficient information exists to permit sustainable harvesting operations in virtually any area of tropical forest world-wide.

- Not just preserving nature, you can save money also through tighter operations as shown in three studies (Marn and Jonkers 1982, Hendrison 1989, Schmitt 1989).
- Need to use the best knowledge available in planning, forest roads, felling, skidding and yarding, and post-harvest assessments.
- Nicholson (1958, 1979) suggests that harvest planning for tropical forests is less now than it was during the colonial era.
- Although harvesting planning implies an increase in initial cost, it can help avoid many problems and costs by reducing wastage and improving efficiency of operations (could cost 20-45% less overall).
- Improper felling can cause damage to pole-size trees, which could be potential crop trees in the future.
- Improper cross-cutting can cause timber wastage and loss of log value.
- Skidders tend to wander through the forest searching for trees, thus resulting in excessive damage to residual trees.
- Post-harvest assessment is necessary to give valuable feedback as to the success or failure of the harvesting operation on long-term sustainability.

Dykstra, D.P. & Heinrich, R. 1996 *FAO model code of forest harvesting practice*. Food and Agriculture Organization of the United Nations, Rome. 85 pp.
- Completely outlines RIL and procedure to follow.
- Experience with training programs to improve crosscutting skills suggest that improved utilization of 20% or more and increased log values of 10-50% can be attained by such training.
- Although skid trails commonly represent 20-40% of the harvesting area, several studies have found 60% or even 80% of the area covered with skid trails after selection harvesting had been completed.

Dykstra, D.P., Kowero, G.S. Ofosu-Asiedu, A. & Kio, P. (eds.) 1996 *Promoting stewardship of forests in the humid forest zone of anglophone West and Central Africa*. The United Nations Environment Programme and The Centre for International Forestry Research, Final Report. 103pp.
- Felling cycle is defined as the period between two successive commercial harvests in the same forest stand.
- The optimum felling cycle is one that ensures complete forest recovery and sufficient stem recruitment into the exploitable diameter class.
- The length of felling cycle is directly related to logging intensity, which is also affected by species composition, stem diameter distribution, total stocking, silvicultural characteristics of desirable species, cost of exploitation and financial needs of the forest owner.
- Felling cycle in Cameroon is 30-60 years.
- Felling cycle in Nigeria is 50 years.
- Felling cycle in Ghana is 40 years.
- Felling limits between 50-110 cm dbh are used in West Africa and vary by country and species (table given in report).
- In south-east Asia 33% of the total area and 33-67% of the residual trees are damaged after logging.

Elias, Ir. 1996 A case study on foret harvesting, damage, structure and composition: dynamic changes of the residual stand for dipterocarps forest in East Kalimantan, Indonesia. In: Proceedings of Forest Operations for Sustainable Forestry, XX IUFRO, World Congress, August 6-12, 1995. IUFRO S3.05-00 and CIFOR Publication. p.13-27.
- Effects of forest harvesting with the Indonesian Selection Cutting and Planting (TPTI) system.
- Almost all the concession holders use the TPTI system.
- Cutting cycle is 35 years and the minimum felling dbh is 50 cm.
- Felling with chain saw and crawler tractor (160 kW) skidding.
- Degree of residual stand damages by plots:

	Slope %	Trees before logging dbh >10 cm	Logging intensity, trees/ha	Percent of residuals damaged
In PT, Narkata Rimba				9.39
I				21.13
II	0-15	620	2	35.43
III	16-25	697	6	
	>25	748	17	
In PT, Kiani Lestari	0-15	565	8	38.60
I	16-25	487	9	46.20
II	>25%	480	8	46.82
III				

- Most of the damage was in smaller trees (NR 65.23% damaged trees with dbh 10-19 cm, and 28-33% in KL).

- 75% of the injuries were caused by skidding and 25% by felling.
- Canopy opening size ranged from 285-512 m^2/tree felled and averaged 396 m^2/tree felled.
- Mortality of residual trees 10-39 cm dbh was 6-26.6% during the harvesting year, 2-13.6% one year after, and 0.7-3.6% two years after.
- Higher damage occurring in residual stands causes the higher tree mortality.
- The mortality of trees in virgin forest was 0.9-2.4% per year (1.1% average).
- At NR the dbh growth of trees with dbh >10 cm was initially 0.55-1.25 cm/year after logging but reduced to 0.41-1.04 cm/year.
- At NR the dbh and volume growth of 25 nucleus trees one and two years after logging were 0.92 and 0.50 cm/year, and 1.832 and 0.901 m^3/ha/year.
- At KL the average dbh growth on trees >10 cm was 0.80-0.95 cm/year after harvesting, and 0.47-0.69 cm/year 4, 9, 13 and 17 years after harvesting; dbh growth in virgin forest is 0.51-0.74 cm/year.
- At KL the average growth of commercial trees with dbh >10 cm was 2.97 m^3/ha/year.

Elias 1999 Introducing a manual on reduced impact timber harvesting in the Indonesian selective cutting and planting system. *ITTO Tropical Forestry Update* 9(3): 26-30.
- Timber harvesting in Indonesia is carried out under the selective cutting and planting system. This system is often considered to cause forest degradation.

Enright, N.J. 1978 The effects of logging on the regeneration and nutrient budget of *Araucaria cunninghamii* dominated tropical rainforest in Papua New Guinea. *The Malaysian Forester* 41(4): 303-318.
- Initial basal area was 42.11 m^2/ha of which 29.4 m^2/ha was *A. cunninghamii.*
- In the logging almost all *A. cunninghamii* were removed (dbh >40 cm).
- Selective logging was very destructive to all size classes of *A. cunninghamii*.
- Of the 168 *A. cunninghamii* individuals (dbh >10 cm), 67 were of commercial size and 64 of these were removed.
- 60 of the remaining 101 trees were destroyed, and by 14 months after felling four more individuals died due to damage sustained during logging (56 remaining *A. cunninghamii*).
- The number of saplings was reduced from 66 to seven, and a further four died by 18 months after logging.
- Of the 143 individuals of non-commercial species (>10 cm dbh) only nine survived.
- Means annual increment in the logged area was 0.71 cm/year and 0.36 cm/year, one and two years after logging.
- Mean annual increments for the corresponding years in the undisturbed site were 0.39 cm/year and 0.42 cm/year.
- Nitrogen and organic carbon levels were back almost to preharvest levels within 18 months.
- Chemicals such as calcium and potassium will take much longer to return to preharvest levels.
- Early secondary tree species rapidly occupy the disturbed sites.
- Under the present logging practices, even where an adequate sapling stand is available, destruction during logging reduces the number of saplings to such an extent that development of a commercially viable stand must start from seed germination rather than sapling development.
- Due to the slow growth rate of *A. cunninghamii* it would be preferable to regenerate the species from saplings since the rotation age could be reduced by 100 years (i.e., eliminate 30 year early successional stage and 50+/-20 years needed for seedlings to read 10 cm dbh).
- Due to the severe logging damage to advance growth, it was estimated that it would take 300 years for the stand to approach its former state due to the slow growth rate of *A. cunninghamii.*

Ewel, J. & Conde, L. 1980 Potential ecological impact of increased intensity of tropical forest utilization. *BIOTROP, Special Publication* No. 11. 70pp.
- Thorough review of the literature on logging impacts in tropical forests with articles ranging from 1909 to 1980 (most articles from 1950 to 1980).

FAO, 1989a *Management of tropical moist forests in Africa*. Food and Agriculture Organization of the United Nations, Rome, Forestry Paper 88. 165pp.
- Soil disturbance 20-25% of logged area.
- The TMF of Africa have a lower stocking of commercial species than in the MDF in south-east Asia.
- Big problem is what share of the growing stock is merchantable, because the varies between locations and between years.
- In the past concessionaires were obliged to plant 3 to 10 plants of the same species for every one which they had felled - this was soon abandoned as a failure because no proven planting technique had been developed and control of operations scattered sparsely over thousands of hectares was impossible.

- Forest services starting doing their enrichment plantings themselves (1930 ...).
- After WWII there was a swing toward natural regeneration (1950-60).
- Again in 1960 results of natural regeneration were judged generally disappointing and the pendulum swung back to plantations in francophone African countries.
- Realization that most of the valuable species in African TMF are light demanders has led to an increasing trend towards planting forest sites after complete removal of the pre-existing forest (timber species on closed forest sites 1,200-2000 USD/ha, pines and eucalypts on savannah sites 700-1000 USD/ha - 1986).
- Well planned and carefully controlled harvesting systems are superior economically, environmentally and silviculturally. Such harvesting systems should be fully integrated with the management system, but has been an elusive goal in the tropics.
- Harvesting problems in the tropics:
    - high rainfall - (1500-4000 mm/year) with little or no dry season, makes felling, extraction, and transport difficult. Even with a good road system, road transport may be limited to 180-220 days a year because of climate
    - topography - a significant part of the forests of Congo, Gabon and Zaire, as well as the montane forests of East Africa, are found on steep slopes
    - difficult soils - (excessively sandy or excessively clayey) which, in conjunction with high rainfall, make logging and transport difficult
    - large tree sizes -
    - long distance to market - in some cases.
    - inadequate knowledge of forest - although a great part of the forests have been inventoried, the intensity of the inventory is often too low to provide acceptable information on stocking on smaller blocks of less than 20,000 ha (sometimes less than 100,000 ha).
    - heterogeneous composition of the forest - commercial volume varies greatly according to proximity to local markets or to ports for export, the sales policy of the concessionaire and the annual fluctuations in the market.
- Total bole volume in francophone African countries average 111 m^3/ha, of which 61 m^3/ha (11.5 trees/ha) is commercial (>70 cm dbh), and of which 15 m^3/ha (2.3 trees/ha) is commercial volume of the preferred species.
- Licenses are not linked directly to regeneration success, therefore, there is no incentive for a concessionaire to minimize damage to residuals and therefore ensure there is volume for future logging operations.
- Every felled mature trees destroys 0.02-0.04 ha of forest, therefore will have some damage to residuals irrespective of what you do.
- Controversy of polycyclic vs. monocyclic silviculture systems - examples of both which have been adopted by countries.
- In polycyclic - must use RIL to maintain at least 15 trees in the 30-60 cm dbh classes, therefore assuming a 30 year felling cycle and growth of at least 1 cm dbh per year there will be a similar volume available as in the first cut (i.e., 15 trees with average dbh of 75 cm will equal same volume as 4-5 trees with mean dbh of 110 cm) - quality will be slightly decreased because of a wider range of species used and smaller log size.
- There is a need for partnership between harvesting and silviculture:
- In Uganda, the current policy is to avoid any system that will tend to convert TMF into single species plantations or even uniform blocks.
- The current rate of harvesting in Nigerian moist forests is so high that almost all the valuable timber will have been harvested by the end of the century.
- In Cote d'Ivoire, silviculture experiments with logging intensity - by removal uncommercial species by 30-40% of the basal area, growth of marketable species increased by 50-100% - indicate that in 40 years they are confident that the majority of stems in the 20-40 and 40-60 cm dbh classes will move up to the next higher size classes.

FAO, 1989b *Review of forest management systems of tropical Asia*. Food and Agriculture Organization of the United Nations, Rome, Forestry Paper 89. 228pp.
- Diversity of the vegetation coupled with the complexity of socio-economic conditions have led to the evolution of a wide spectrum of management systems. However, what is actually practiced seldom fits into the description usually found in silviculture text books and often represents a compromise between conflicting factors.
- Felling rules in Kerala (no two trees within 20 m of each other may be felled/climber cutting at time of marking to reduce felling damage/no felling 20 m on either side of a watercourse/marking done so no lasting gaps in canopy/only dead or dying trees marked on slopes).
- In addition all broken or completely damaged trees are to be cut back.

- Although only a few trees are felled damage to other standing trees is very high (e.g., if only 10 trees/ha felled, sometimes this results in opening the canopy to the extent of 50%).
- Drastic increase in light and change in moisture conditions encourage the growth of weeds, especially primary colonizers, impeding the establishment and growth of regeneration.
- Selective felling with sufficiently long cutting cycles on moderate slopes seldom causes any erosion problems.
- Contractors (employed by both the State (India) and private companies) are primarily interested in profit maximization, to the neglect of silvicultural prescriptions.
- Clear felling adopted in India to maximize yields.
- Malaysian Selective Management System (SMS) - based on inventory data - minimum dbh cutting limit 50 cm in dipterocarps and 45 cm in non-dipterocarps.
- Results from 100-0.4 ha continuous inventory sample plots and another 100 experimental cutting and/or silvicultural treatment plots (4 ha each), give following data for trees >30 cm dbh) - Malaysia:

Diameter growth in cm/year	
a) all marketable species	0.80
b) dark/light and red meranti	1.05
c) medium-heavy marketable species	0.75
d) light non-meranti marketable species	0.80
e) non-marketable species	0.75
Gross volume growth in m^3/ha/year	
a) all marketable species	2.20
b) all species	2.75
Gross volume growth %	
a) all marketable species	2.1%
b) all species	1.9%
Annual mortality % of number of marketable species	0.9%
Annual ingrowth % of marketable species growing >30 cm dbh	0.6%

- Preliminary studies have assessed felling damage to remaining intermediate sized trees of >30 cm dbh to be 30%.
- Wastage due to breakage and bucking: 6.5-8% of the gross timber volume.
- Need more effective use of directional felling.
- In Malaysia minimum cut to be economic estimated to be 35-40 m^3/ha, with periodic cuts every 35-40 years.
- Logging cycle in Malaysian Peninsular hill forests could be 30 years, and the cut should be 40-45 m^3/ha of currently marketable and utilizable species (assuming 0.8-1.0 cm diameter growth per year = 2.0-2.5 m^3/ha/year in commercial gross volume).
- However, it is necessary to limit logging damage to residual stand to not more than 30% of intermediate sized trees.
- Sabah - Modified Malaysian Uniform System explained.
- Sarawak - Malaysian Uniform System explained.
- Philippines - selective logging if properly implemented is still regarded as the best silvicultural system applicable to the Philippine dipterocarp forests.
- For 1974-1983 forest destruction occurred over an average 21% of the area logged per year, leaving an adequately stocked logged-over area of 79%.
- These forests should yield and adequate logging volume after 30, 35, 40 or 45 years.
- In ground-based systems 54.5% of residuals undamaged, while with high-lead yarding 43.3% undamaged.
- Could have 1-2 improvement cuts between logging cycles to help improve the stand, cut vines, etc.
- The disappointing results of the early attempts to transpose the Malaysian uniform system to West Africa, where the canopy opening led more often to climber tangles than to established regeneration, show the high degree of sensitivity to this distinction. A very substantial jump in the uncertainty, as well as the difficulty of management is clearly associated with systems depending on induced regeneration as compared with release. So much so, that it could well be that the Dipterocarps are a fortunate exception; perhaps one of the few types of the tropical mixed forest, in which, given the present state of ecological knowledge, natural management systems can be confidently advocated and put into effect.
- In India, the unreliability of regeneration reinforced the trend towards plantations. Pessimism about the prospects for the management of the tropical mixed forest where regeneration is not readily assured might therefore be justified. Fortunately, there are several indications to the contrary.

- Tropical shelterwood system in West Africa lead to more often than not, to the successful establishment of a satisfactory second crop, and that crop had all the signs of being a more productive one than the forest it replaced.
- Uneasiness in India, Philippines and Malaysia in regard to the low yield of the natural tropical forest (e.g., 20 m^3/ha over 30-40 years).
- Shortening the felling cycle and increasing the logging intensity in natural tropical forests will lead to the vicious cycle of liquidation.
- Have to careful about increased use of lesser known species to increase logging intensity, but could be useful to decrease the demand in the same forest for the high-value commercial species (i.e., ensure they are still available into the future).
- This could lead to more damage and environmental impact.
- Nicholson (1979, 1985) extremely sceptical of the chances of raising the increment of the Dipterocarp forests to more than 2-3 m^3/ha/year. The fact that after a century or more of management in India, the average increment for the natural forests is still only 0.5 m^3/ha/year.
- If all you want is wood fibre then plantations come into question, although it is possible to grow saw logs and veneer logs in plantations on longer rotations (5 to 10 times increase in increment when compared to a fully managed tropical mixed forest).

FAO, 1991 *Forest management research and development, Papua New Guinea: Project findings and recommendations*. Food and Agriculture Organization of the United Nations, Rome, Project FO:DP/PNG/84/003, Terminal Report. 61pp.

- The terminal report of a series of 16 reports on forest management, mensuration, logging operations and silviculture in PNG.
- Although the intensity and standards of logging and log marketing vary from company to company, there has been an increase in the number of species harvested and number of trees harvested per hectare.
- Over 400 species are known to have commercial value, and of these, about 70 are regularly marketed.
- Logging is very selective with a minimum felling limit of 50 cm dbh (59 m^3/ha +/- 13.3 m^3/ha), although companies dealing with export markets maintain a 60 cm limit and the average logging intensity is 30 m^3/ha (companies rarely log areas with less than 20 m^3/ha).
- Potential yields are 50% greater (i.e., 45 m^3/ha) if all available commercial species were harvested down to a 50 cm diameter, and unnecessary wastage caused by high stumps, poor felling technique, excessive trimming and inefficient bucking into commercial lengths were removed.
- Experience in other countries has shown that with good control of selective logging the average commercial wood yield expected is an average from 0.5 to 2 m^3/ha/year, with a logging cycle from 20 to 40 years.
- This same experience has shown that the forest will recover after poor logging but this adds another 10-20 years to the logging cycle due to the loss of advanced growth required for the next cut; poor logging practices are more likely to result in undesirable changes in species composition.
- Could have stumpage rates by species (i.e., higher quality and larger trees have higher stumpage rates and poorer quality trees lower stumpage rates to encourage their use).
- Could have variable minimum dbh felling limits by species (i.e., pioneer species can be felled at smaller dbh).
- All improvements, stand marking, etc. require close supervision and cannot be left to the logging contractor.
- A problem which has occurred almost everywhere where stand improvement has been used in the tropics, is that many trees which were killed as useless would have been marketable in the next cutting cycle if they had been left.
- Old natural forest often seems to be saturated with basal area so that growth ceases except in the vicinity of fallen trees. It follows that tending must aim to keep the basal area below this saturation level and until research determines more precisely what this level is an arbitrary figure of 30 m^2/ha is a useful index to apply.
- Current practice in most logging operations is basically very poor and the impact has adverse effects on the sustainability of the forest resource and the stability of the environment.
- Shortcomings are marked by a lack of adequate planning, lack of experienced technical staff and past liberal policies in control.
- Alignment and construction of forest roads and skid trails are very variable and result in excessive damage to the forest; a result of a lack of adequate forward planning and control.
- Trees are felled in the direction most convenient to the chain saw operator and this frequently results in unnecessary damage being caused to the tree and its neighbours.
- High stumps and bucking to a 40 cm top results in considerable waste, with further losses in excessive trimming, lost logs and unfelled trees of commercial quality.
- Unnecessary forest loss occurs due to too frequent and too large log landings.

- The >30% of area covered by roads, skid trails and landings can be reduced to <15%.
- In each case study it was apparent that planned logging operations can effectively reduce the area of land assigned to roads and landings.
- Skidder production is increased in planned operations from 8.42 m^3/machine hour to 12.1 m^3/machine hour (43.7%).
- Better planning and control can result in less machine time required and consequently fewer machines required, forward marking can be practiced, and damage to the forest is reduced with a resultant saving of residuals for the next cycle of logging and the environment is protected.
- Maximum basal area CAI is at about 50 cm dbh, while maximum basal area MAI increment is at about 60 to 70 cm dbh.
- The MAI at its worst will be 0.6 m^3/ha/year and best 2.5 m^3/ha/year, and the logging cycle will be from 30 to 40 years.
- A felling cycle of 30 years should be used for tactical planning and 40 years for strategic planning, as currently adopted by the Department of Forests.
- It is also justified to use a volume increment of between 0.8 and 1.7 m^3/ha/year for predicting future volume availability.
- Good controlled logging is the only realistic silvicultural tool available for the management of the natural forests.
- Planning is essential if logging operations are to be applied in an orderly manner and damage to the forest and the environment reduced to a minimum.

FAO. 1997a *Forest harvesting in natural forest of the Republic of the Congo. Forest Harvesting Case Study # 7*. Food and Agriculture Organisation of the United Nations. Rome.

- The study was carried out in a closed-canopy, broad-leaved forest located in southern Congo at the border to Gabon.
- The average harvesting intensity was 5.8 m^3 net log volume or approximately 1 tree/ha.
- The study inventory revealed an average density of 455 trees/ha of which 3.3% was Okoume (*Aucoumea klaineana*). The felling limit was set to a minimum of 80 cm dbh.
- The total recovery, expressed as net log volume compared to the standing stem volume (including stump, up to the first branch of the crown) was 70%.
- The average damage frequency was 17.7 damaged trees per tree felled (approximately 3 trees damaged per cubic metre removed).
- The damage rate to residual Okoume trees was 3.3% with the majority of damaged stems in the higher dbh classes.
- Skidding damage occurred with a frequency of 11.5 trees/ha (proportion of Okoume 2.8%).
- 46% of all trees damaged during skidding operations were fully or partly uprooted.
- The overall damage frequency for Okoume in all diameter classes was 7.2% and for those trees 40-80 cm dbh (immature future crop trees) it was 9%.
- The damage frequency for all species and size classes was 6.3%.
- Soil disturbance was recorded on 8.4% of the total area. Felling sites accounted for 3.8%, skid trails for 2.7%, secondary roads for 1.0%, primary roads for 0.7% and landings for an estimated 0.2%.
- A more detailed survey shows that 0.9% of the area were seriously disturbed by skid trails and landings (mineral soil exposed) and 5.8% of the area were slightly disturbed by felling sites and skid trails.
- According to a pre-harvest survey the average density of harvestable trees in the study area was less than one tree per hectare.
- The harvestable volume (_80cm dbh) of Okoume was 11.8 m^3/ha (total volume of Okoume 37.5 m^3/ha).
- The average wood recovery rate was 86% after felling and 70% after crosscutting. The loss of 14% of the volume during felling was due to stump wood and stem wood that does not meet the quality requirements. The possibilities for increasing felling recovery are very limited, since the stump wood is not considered usable.
- Assuming an average skid trail width of 4m, the area covered by skid trails is approximately 2.7% of the total area.
- The road and skid trail network, including landings, covers approximately 4.6% of the total surface of the study area.

FAO. 1997b Harvest Impacts. *Forest Harvesting Bulletin* 7(1): 1-4.

- <u>Eastern Amazonia:</u>
    - Three felling intensities were used where 20, 40 and 60% respectively of all trees over 40cm dbh were harvested.
    - The impact on the soil was examined both in dry and rainy seasons (soil moisture 39-43% and saturated respectively).

- Concentrating vehicle movement on skid trails can reduce the total area of compacted soils.
- The use of a smaller diameter winch line allows for an increase in the distance between skid trails.
- Poorly positioned logs and communication problems between choker setter and skidder operator were the main reason of damage to the residual stand.
  Increased traffic caused an increase in mechanical and shear forces down to a soil depth of 20cm and a decrease in water conductivity and air permeability.
- Water conductivity and intrinsic air permeability were reduced drastically after the first pass of heavy machinery.
- Signs of compaction were still found 12 years after the skidding occurred.
- The position of the log after felling is directly correlated with the degree of damage caused by extraction and with operational productivity.

• East Kalimantan, Indonesia (STREK project):
- Primary and secondary mixed lowland dipterocarp forests covered the study area.
- RIL techniques were applied with two diameter limits (50 and 60cm dbh respectively).
- The net annual increment increased from 0.7 m^3/(ha*a) to 1.3 m^3/(ha*a) with the transition from conventional logging to reduced impact logging.
- Logging damage to the residual stand can be reduced from 40-50% to 25-30% if several recommended improvements to conventional logging methods are implemented.

• East Kalimantan, Indonesia:
- This study analysed the impact of conventional and reduced impact wood harvesting within the Indonesian Selective Cutting and Planting System>
- The following data summarise the results of the impact study:

	Method of Harvesting	
Impact Results	**Conventional**	**Reduced Impact**
Residual stand damage by stage of vegetation (%)		
- Seedlings		
- Saplings	33%	18%
- Poles and trees	35%	20%
	40%	19%
Tree damage based on injury size (%)		
- Light and medium injury	12%	7%
- Heavy injury	29%	12%
Canopy opening (%)		
- Caused by felling	11%	8%
- Caused by skidding	9%	5%

• The comparison of production costs shows no significant difference between conventional and reduced impact harvesting methods.

FAO 1997c *Environmentally sound forest harvesting. Forest Harvesting Case Study # 8*. Food and Agriculture Organisation of the United Nations. Rome.

• This study was carried out in the Amazon region of Brazil, testing the applicability of the *FAO Model Code of Forest* Harvesting Practice.
• The planned harvesting cycle is 25 years.
• The average harvesting intensity is 35 m3/ha with a maximum of 40 m3/ha (about half of the average harvestable volume per hectare found for the project area).
• For the environmentally sound forest harvesting system, 33% of the timber volume found by the commercial inventory prior to harvesting was removed (equals 26% of the trees of commercial interest).
• In conventional harvesting operations 73% of the timber volume was removed (69% of the trees of commercial interest).

- Classification and percentage of workplace time consumption:

	Reduced impact logging	Conventional logging
Work time	17 h 15 min	13 h 34 min
Non-work time	40 min	26 min
Workplace time	17 h 55 min	14 h 00 min
Trees felled	44	43
Trees only bucked	6	2
Trees harvested	50	45
Trees rejected	19	2
Utilisable volume	353.90 m^3	250.81 m^3
Volume/tree	7.08 m^3	5.57 m^3
Time required for felling a single tree	21.41 min	17.59 min
Productivity for felling	19.76 m^3/h	17.92 m^3/ha
Time required for extraction of a single log	9.27 min (pre-skidding)	10.35 min
	4.27 min (skidding)	
Productivity for extraction	31.04 m^3/h (pre-skidding)	24.90 m^3/h
	65.53 m^3/h (skidding)	

- The estimation of production costs is based on the productivity for harvesting operations as stated above. The hourly cost estimates are based upon information obtained from the company:

	Reduced impact logging		**Conventional logging**
	Actual production cost (%)	**Planned production cost (%)**	**Production cost (%)**
Commercial inventory	15	16	-
Forest road	24	26	27
Road maintenance	6	7	-
Trail pre-opening	4	3	-
Felling	12	9	10
Pre-skidding	29	28	-
Skidding	10	11	63
Total	100	100	1000

- Referring to the costs of the conventional logging system per cubic metre of saw log at landing site as 100%, the costs the of environmentally sound forest harvesting system come to 109% and would amount to 101.5% of the environmentally sound forest harvesting system had been carried out according to the planned changes.
- Severe harvesting damage to potential crop trees was more than two times higher in the conventionally logged unit than in the unit harvested according to RIL guidelines (In the reduced impact harvesting operation 19.5% percent of the potential crop trees were damaged during felling and 2.7% during skidding. In the conventional logging operation 32.3% of the potential crop trees were damaged during felling and 19.8% during skidding).
- Two years after harvesting the plant density in skid trails was about two times higher than in gap openings. Soil compaction did not seem to have an influence regarding plant density.
- In the reduced impact logging unit the area occupied by skid trials amounts to 4.2% of he total area, whereas in the conventional logging system the affected area amounts to 18.7%.
- Measurements carried out one week after skidding indicate that soil compaction as found after several skidder passes severely restricts the infiltration of water into the ground.
- Dragging of heavy logs (e.g. cableways) also considerably diminishes the infiltration rate.
- The total timber losses amounted to 8.5% in the conventionally logged area and 3.9% in the reduced impact logging area. Losses due to forgotten logs did not occur since all trees had been numbered prior to harvesting.
- The most important cause of timber loss in the reduced impact logging system was unsatisfactory crosscutting and topping. This could have been avoided by using a measuring tape.

- Reduced impact logging caused canopy gaps totalling 10.8% of the area (mean size 174 m^2, maximum size 532 m^2), while conventional logging resulted in canopy gaps on 24.7% of the area (mean size 150 m^2, maximum size 317 m^2).
- Severe harvesting damage to potential crop trees was found to be more than twice as high in conventionally logged areas (51.5%) as compared to the environmentally sound forest harvesting system (22.2%).

FAO, 1997d *State of the World's Forests: 1997*. Food and Agriculture Organization of the United Nations, Rome, Italy. 200pp.

- 3 454 million ha (1995) of forest area or 26.6% of total land area of the world (Greenland and Antarctica excepted).
- Temperate and boreal forests 1.64 billion ha and tropical forests 1.76 billion ha.
- Many improvements in tree-felling operations, extraction systems and forest road construction have come about as a result of efforts to minimize the negative environmental impacts.
- Evidence from studies done in various countries suggests that environmentally-sound forest harvesting practice may be only marginally more expensive than traditional methods.
- However, there are clear economic and ecological benefits arising from the reduced damage of both felled and residual trees, smaller areas needed for roads, skidtrails and loading/landing areas, and reduced wood waste.
- Dykstra (1992) - of all the wood felled annually for timber in tropical forests, about half remains in the forest as unused wood residues.
- Need for improvements in tree-felling operations (cutting of climbers and vines before tree felling, directional felling).
- Recent studies on improved tree felling techniques show increased wood volume recuperated of up to 30% and that damage to the residual forest stand can be reduced by more than 20%.
- Low impact wood extraction systems, better planned skid trails and forest roads, environmentally-acceptable harvesting and forest engineering operations are gradually being adopted by forest owners and contractors particularly, but not only, in the developed world
- See Boulter above in regard to sawn wood.
- In the manufacture of paper and paperboard pulp from chips and round wood only made up 56% of the furnish in 1994, where in 1970 it was 75% (i.e., increase use of recycled fibre, non-wood fibres and other additives (e.g., clay)).
- Global round wood consumption 1994 was 3.21 billion m^3 (fw 1.890 and irw 1.476 billion m^3).
- Forecasted round wood consumption 2000 is 3.512 billion m^3 (fw 1.885 and irw 1.627 billion m^3).

FAO. 1998 Reduced impact timber harvesting in the tropical natural forest in Indonesia. Forest Harvesting Case Study # 11. Food and Agriculture Organisation of the United Nations, Rome.

- The study was carried out in East Kalimantan and compares conventional and reduced impact timber harvesting within the Indonesian Selective Cutting and Planting system.
- The objective of the study was to test the applicability of the *FAO model code of forest harvesting practice 1996.*
- The cutting cycle was set at 35 years.
- Productivity of felling in conventional and reduced impact timber harvesting:

	Average dbh (cm)	**Volume per tree (m^3)**	**Time required (min/tree)**	**Productivity (m^3/h)**
Conventional harvesting	68.42	4.00	16.9	14.20
Reduced impact harvesting	61.58	3.69	18.0	12.30

- Productivity of skidding in conventional and reduced impact timber harvesting:

	Volume per load (m^3)	**Time required per trip (minutes)**	**Productivity (m^3/h)**
Conventional harvesting	4.11	38.14	6.47
Reduced impact harvesting	4.03	33.01	7.33

- Performance was about 100m^3/h for bucking, 15 m^3/h for debarking and 72- 76 m^3/h for loading (conventional harvesting).
- The productivity of skidding in reduced impact harvesting is about 13% higher than in conventional timber harvesting.

- The total cost of timber harvesting in conventional logging operations is 2.94 US$/$m^3$, while in reduced impact timber harvesting it is 2.97 US$/$m^3$ (this does not include the topographic maps and timber harvesting planning costs).
- Assuming a profit ratio of 30%, the timber damages value caused by conventional timber harvesting is twice greater than the timber damages value caused by reduced impact timber harvesting (2.94 US$/ha : 1.29 US$/ha).
- The size of the opened areas caused by felling of one tree in conventional logging is 300m^2 and in reduced impact logging it is 212.9 m^2.
- With a harvesting intensity of 3-4 trees/ha, the opened areas caused by felling in conventional timber harvesting is 11.10% and in reduced impact logging is 7.65%.
- With a harvesting intensity of 3-4 trees/ha, the opened areas caused by skidding in conventional timber harvesting is 8.73% and in reduced impact logging is 5.21%.
- With a harvesting intensity of 3-4 trees/ha reduced impact logging can diminish by up to 35% the opened area otherwise caused by conventional timber harvesting.
- As compared to conventional timber harvesting, reduced impact logging can lessen damage up to 50% - without a significant productivity decrease- through a series of timber harvest plans and techniques, such as: cutting of vines, directional felling, skid trail planning and construction and proper skidding.

FAO 1999 *Environmentally sound forest infrastructure development and harvesting in Bhutan. Forest Harvesting Case Study # 12*. Food and Agriculture Organisation of the United Nations. Rome.

- This study was carried out in natural forests of the Himalayan range in Bhutan, focussing on "Environmentally Friendly Forest Engineering".
- A productivity of 3.88 m^3/h was found for cable logging applying the traditional clear felling practice. The corresponding figure for the group selection felling system was 5.01 m^3/h.
- The costs per cubic metre of timber extracted by long-distance cable crane amounts to US$ 25.53/m^3 for the traditional system and US$ 20.13/m^3 for the group selection system.
- The production rates for road construction were 6.72 m/h for construction by excavator and 15.19 m/h for construction by bulldozer.
- The total costs were US$ 9.28/m for excavator construction and US$ 6.07/m for bulldozer construction.
- Focussing on environmental impacts of road construction, the superiority of the excavator technique in difficult and/or steep terrain over bulldozer construction techniques becomes obvious, although the short-term benefits might favour the use of bulldozers.

FAO 1998 *Carbon dioxide offset investment in the Asia-Pacific forestry sector: opportunities and constraints*. *RAP Publication 1998/9, RWEDP Field Document No. 53.* Food and Agriculture Organisation of the United Nations. Bangkok, Thailand.

- There is an increasing interest in using carbon offset financing to carry out more environmentally sound forest management.
- Conventional logging practices release large volume of greenhouse gases through the rapid decay of trees and other vegetation and soils damaged or disturbed during logging operations.
- Putz and Pinard (1995) suggest that conventional logging operations damage up to 70% of the residual trees in harvesting areas.
- Reduced impact logging is an attractive carbon offset option because 50% of the green-house-gas-benefits are realised over the first few years.
- A basic attraction of RIL, particularly for governments, is that forests continue to provide economic potential through timber production while improving the environmental value.
- RIL techniques are cost intensive. If paid for with carbon offset money the implementation must be closely monitored. RIL provides little monetary incentives for forest concessionaires to invest in these techniques.
- Indonesia: In the lowland dipterocarp forest of East Kalimantan, RIL will be introduced on 600ha. It is estimated that logging damage to the remaining biomass can be reduced by as much as 50% through vine cutting, directional felling, proper construction of skid trails and carefully planned extraction. Project developers believe this project will generate savings of 56,400 tons of carbon over its projected 40-year period. Without outside financing the incentive to expend resources on improved management is minimal. A carbon investment would provide training as well as pay for various RIL activities.
- Malaysia: After a pilot stage of 3 years which covered an area of 1400 ha, the calculated greenhouse-gas-benefits were sufficiently positive to warrant the concession for implementing reduced impact logging on up to 9000 ha over the coming three years. The approximate cost, based on greenhouse gas savings, is around US$ 1.40 per ton of CO_2.

Fath, H. 2002 *Commercial timber harvesting in the natural forests of Mozambique. Forest Harvesting Case Study 18*. Food and Agricultural organization, Rome.

- In order to establish information on the efficiency of commercial forest harvesting, the present study analyses five enterprises in northern, central, and southern Mozambique. Efficiency is evaluated by means of operational, organisational, energy, and financial indicators.
- Operational data were collected through time studies with continuous timing. Costs per machine-hour were calculated with the "Production and Cost Evaluation Programme – PACE" (FAO 1992). Intermediate results on output (log volume, travel distance) were then related to those on input (work-cycle time, tree volume, logged area, workforce, equipment, fuel consumption, costs per machine-hour), yielding indicators for operational efficiency (productivity, recovery rate, extraction intensity), organisational efficiency (labour productivity, utilisation rate, capital intensity), as well as for energy and for financial efficiency (unit costs, break-even point).
- Logging operations, although well synchronised and productive within work cycles, occurred in a scattered and unsystematic scheme. Lack of harvest preparation, low recovery rates, and improper working techniques in felling and crosscutting resulted in low extraction intensity. Transport was the main bottleneck in operational efficiency. Poor road conditions and low load capacities of vehicles used in first (short-distance) transport and second (long-haul) transport prevented a consistent flow of raw materials and consequently held annual production volumes well below technological capacities.
- As to organisational efficiency, only one enterprise showed favourable results in utilisation rate as well as in labour productivity and capital intensity.
- The other enterprises in the study, because of hampered raw-material flows, excessive numbers of personnel, and low timber potential in the logging areas, scored poor rates between timber output and input of equipment and workforce.
- Indicators for energy efficiency in logging and first transport displayed favourable ratios between calorific values of produced timber and those of consumed energy. However, high fuel consumption and low productivity in second transport and processing precluded efficient energy use for the operations as a whole.
- Financial efficiency varied depending on production volume, the degree of conversion of the final products, and the distance between the logging area and sawmill or sale site.
- Second transport and processing incurred the largest share of production costs per unit. In most cases low annual production volume and low productivity in transport and processing boosted unit costs and created pronounced deficits.
- Only one company managed to limit unit costs and create profit by efficiently employing machinery and workforce, producing on a comparably high volumetric level and externalising second-transport and processing costs to the buyer. Break-even points were in most cases beyond actual production volumes but still within limits of technological capacity.
- Due to higher prices obtained for finished products and lower transport costs, enterprises processing timber near the logging areas would have attained break-even point at a lower production level than those selling logs far from their origin.
- As a consequence of operational and organisational impediments, production was extensive in terms of extraction volume and intensive as to workforce, energy, and capital.
- Results suggest that the efficiency of commercial timber harvesting, as it was practised under the conditions observed during this study, generates little or no benefit and hardly justifies extracting resources which should be considered precious and polyvalent assets for rural communities, the national economy, and the global biosphere.
- Recommendations from the study focus on raising extraction intensity through harvest preparation and optimised use of all available commercial species, and on reducing production costs by restricting transport distances and allocating processing units as close as possible to logging areas.
- In order to guarantee operational, organisational, energy and financial efficiency, commercial timber harvesting should be confined to areas rich in commercially valuable tree species, and conducted by means of systematically structured and operationally optimised procedures.
- Further studies are required to verify whether more efficient logging practices would comply with standards on reduced environmental impacts and socio-economic performance.

Fearnside, P.M. 1989 Forest management in Amazonia: the need for new criteria in evaluating development options. *Forest Ecology and Management* 27(1): 61-79.

- Sustained management of Amazonian forest is non-existent on a commercial scale and is in its infancy as a research front.
- The low priority that has been given to developing and implementing sustainable systems is a reflection of the low weight given to future costs and benefits in presently-used economic calculations.
- Problems include the lack of connection between discount rates applied to future returns and the biological rates limiting forest growth, inappropriate accounting for environmental and social factors and common property effects.

- When standard discount rates (i.e., 10%/year) are compared with returns from the forestry sector (in the order of 3%/year), the forest is sacrificed for unsustainable uses with higher short-term returns.
- Ways of shifting the balance toward sustainable management include:
    - use of a lower discount rate for judging forestry projects.
    - adjust present value calculations to correct for expected increases in the value of forestry products relative to other commodities.
    - increasing the weight given to future costs.
    - using shadow prices in the calculations to reflect forestry's social benefits.
    - assigning additional weight to irreversible costs such as species extinction.
- Lists a number of cases where good forest management practices in the tropics have been thwarted due to political instability or other reasons.
- Government agencies give virtually universal endorsement to the goal of sustained forest management but do not match these ideals through budgetary allocations or other concrete actions.
- Logging operators make no effort to determine sustainable use intensities or to restrict their activities to such limits. Although frequently decried as `irrational', this behaviour is in fact quite logical under the current system of economic decision rules.
- Rapid discounting of future returns leads to decisions to harvest natural populations at unsustainable rates, leading to elimination of populations and the extinction of species when the discount rate is more than twice the maximum reproductive potential of the population.
- Another problem is known as the `common resource dilemma', the `prisoner's dilemma' and the `tragedy of the commons', where independent nations, firms and individuals harvest a population as quickly as possible, although knowingly destroying the resource because each perceives that the others will do so anyway.
- Applying NPV is often flawed by less-than-full weight being applied to risk and uncertainty.
- Sustainable forest management should be most attractive to large firms, since the principal attraction of this land use is its offer of long-range stability rather than quick profits.
- The large areas required to guarantee an adequate harvest rotation also make big operations most appropriate.
- Individuals can however join together to form co-operatives of sufficient size, given the proper institutional support.

Fearnside, T. 1995 Australian hardwood logging and the sustainable harvesting of tropical rainforest. *Commonwealth Forestry Review* 74(3): 204-207.

- As in other developed countries, the factors which are shaping logging practices in Australia include new government policies, economic considerations, technical and organizational changes, and a greater awareness of environmental factors at all levels of the community, not least the `green movement'.
- In the coastal tropics the major disturbance is by wind and cyclones.
- If openings in these forests are too large, they become invaded by creepers or pioneer species of little timber value.
- Need planning, marking of trees and directional felling.
- Helped in Australia with new GIS and GPS technology to mark trees on maps of scale 1:10000.
- Also been benefits of these technologies in Fiji, however, these resources are rarely available in developing countries.
- Also a problem of using GPS in a closed canopy tropical rain forest.
- Need a broad, not necessarily a detailed, understanding of the ways in which the forests regenerate after natural disturbance.
- Need clear prescriptions for the country and forest in question.
- Need sound planning and management of logging operations.
- All stakeholders must be environmentally aware.

Fickinger, H. 1992 Zur Verjungung einiger Wirtschaftsbaumarten in selecktiv genutzten Feuchtwaldern der Republik Kongo (Regeneration of some commercial tree species in selectively logged rain forests in the Congo). Gottinger Beitrage zur Land und Forstwirtschaft in den Tropen und Subtropen, No. 75. 226pp.

- Removed 1-2 trees/ha (=10-15 m^3/ha, dbh>80 cm) on a 30-35 year cycle.
- The selective logging did not induce regeneration of three (commercial?) species in the gaps and involved a loss of biodiversity.
- Accordingly, any form of utilization that relies on natural regeneration must be based on a wider range of species, and measures must be taken in the interval between the logging operations so as to establish adequate regeneration and concentrate increment on the commercial species.
- Expected rotation age for individual trees is 100 years for a dbh from 70-80 cm.

Foahom, B., Jonkers W.B.J. & Schmidt, P. 2002 Unravelling the complexity. *ITTO, Tropical Forest Update* 11 (4): 7 – 9.

- The Tropenbos Cameroon Program (TCP) together with ITTO commenced a program in 1994: 'Development of methods and strategies for sustainable management of moist tropical forest in Cameroon'.
- The study was conducted about 80 km East of Kribi in South Cameroon.
- Results indicated that improved planning, training and control could substantially reduce the area disturbed by skid trails and landings.
- Approximately 15% of harvestable timber was not harvested in the Wijma concession and only 70% of timber felled was actually delivered to the sawmill.
- Construction of roads and tracks should be avoided or minimized on slopes steeper than 10o to prevent excessive erosion.
- Liana cutting before logging did not reduce the size of canopy gaps.
- Income could be increased by reducing waste.

Fox, J.E.D. 1968 Logging damage and the influence of climber cutting prior to logging in the lowland dipterocarp forest of Sabah. *Malaysian Forester* 31(4): 326-347.

- The levels of damage have increased over time and not merely due to increased basal areas being extracted.
- This damage is of concern as it will obviously mitigate against any attempts at selection working or of reducing the period of time between harvests.
- Some control of tractor working is essential if damage is to be reduced.
- When climbers were cut, 42.5% of residuals had little or no damage; with no climber cutting 26.1% had little or no damage (logged 1966), but results from 1958 showed 55% with little or no damage.
- Volumes extracted in treated in ft3/acre (1752, 1780, 1788, 912, 1538, avg = 1554).
- Volumes extracted in controls in ft3/acre (2164, 1435, 1891, 3008, 2004, avg = 2100).
- Considerable seedling loss due to tractor movement and approximately 43% of the sampled squares were damaged by machinery.

Fox, J.E.D. 1968 Defect, damage and wastage. *Malaysian Forester* 31(3): 157-164.

- Considerable quantities of timber are at present left in the forests of Sabah.
- Due to difficulties of marketing little known or uncommon, or small-sized species, considerable quantity of defective wood either through insects or decay, and a large proportion is lost through damage in falling, as top or bottom pieces bucked off or, less often, as bent pieces.
- Generally logging intensity is 89 m^3/ha, though stands may reach 267 m^3/ha.
- 80% of more of the stand over 60 cm dbh is generally dipterocarps.
- The top diameter is 48 cm, but sometimes smaller material is removed (though will be hard to sell).
- No attempt is made to extract logs that have split on felling or cross-cutting.
- After harvesting there should be 40 +/- 9.4 dipterocarp trees/ha of 10-50 cm dbh left as residuals.
- Only 33.6% of the residuals had little or no damage, while 53.5% were fallen or broken off, and 12.9% had major crown and/or bark damage.
- Of 42.5 potential dipterocarp residual crop trees/ha in the study area, only 14.3 trees/ha had little or no damage.
- It is generally accepted by progressive companies in Sabah that felling near the ground tends to reduce damage due to falling: i.e., shatter, splitting, broken logs, torn bases.
- For trees felled at 7 ft or more 50% were damaged significantly or severely.
- For trees felled at 6 ft or less 21% were damaged significantly or severely.
- However, a review of the information presented indicates that not much weight can be given to the above trend (i.e., 125 trees <= 6 ft felling height vs. 12 trees >=7 ft felling height).

Fredericksen, T.S. & Putz, F.E. 2003 Silvicultural intensification for tropical forest conservation. *Biodiversity and Conservation* 12: 1445 – 1453.

- Minimizing the negative environmental impacts of logging and other silvicultural treatments is the primary conservation goal in tropical forests managed for timber production.
- While it is always environmentally beneficial to minimize unnecessary damage, more intensive silviculture should not be discouraged in tropical forests in which regeneration and growth of commercially valuable timber species requires such treatments.
- Failing to regenerate commercial species may render forests more susceptible to conversion to other, more lucrative land uses.

Fredericksen, T.S., Putz, F. Pattie, P. Pariona, W. & Pena-Claros, M. 2003 Sustainable Forestry in Bolivia – Beyond Planned Logging. *Journal of Forestry* March 2003 : 37 – 40.

- Forestry in lowland Bolivia has taken strides in the past few years, progressing from a virtual absence of management to a system of regulated management planning.
- Nearly 1 million hectares of forest are now certified by the Forest Stewardship Council.
- To ensure sustainable forest management, however, Bolivian foresters need to go beyond the basics of planned logging and apply silvicultural treatments to secure regeneration, improve tree growth and maintain stand quality.
- This change is a tall order in a developing country battered by a deep economic recession, where timber-mining interests are still powerful and silviculturists are in short supply.

Fredericksen, T.S. & Pariona, W. 2002 Effect of skidder disturbance on commercial tree regeneration in logging gaps in a Bolivian tropical forest. *Forest Ecology and Management* 171 (3):223 – 340.

- The impact of skidder disturbance on recruitment of commercial tree regeneration within logging gaps was studied using paired scarified and unscarified plots as well as whole-gap surveys of scarified and unscarified areas in a Bolivian tropical humid forest. More than a year following gap creation, variability in the density of regeneration among logging gaps was high, but commercial tree regeneration density tended to be greater in scarified areas than in unscarified areas within gaps for most species. Height growth was also significantly greater for trees in scarified compared to unscarified areas, despite a near doubling of soil compaction in scarified areas. The principal species benefiting from soil disturbance by skidders was *Schizolobium amazonicum*, which had nearly 10 x higher density and 2 x greater height growth in scarified, compared to unscarified areas. Although initially devoid of vegetation and litter cover, scarified areas had vegetation and litter cover levels similar to unscarified areas after 7 months. Vegetation cover on scarified areas tended to be dominated by early successional tree species while unscarified areas were dominated by forbs and grasses.

Fredericksen, T.S. 2000 Limitations of low-intensity selection and selective logging for sustainable tropical forestry. *Commonwealth Forestry Review* 77(4): 262-266.

- In selection systems, individual trees are selected for harvesting with the intention of maintaining sustained yield. In contrast, selective harvesting involves cutting trees based on economic considerations of stem size and/or quality without respect to sustained yield.
- Van Gardingen (1998) observed an absence of regeneration of dipterocarp seedlings on sites with soils disturbed by logging and in large logging gaps.
- It may be preferable to reduce the rate at which new areas are logged by practising more intensive logging in areas currently being harvested.
- Findings by Lugo (1995) indicate that tropical forests are surprisingly resilient to disturbances on a much larger scale than those created by single treefalls.

Gajaseni, J. & Jordan, C.F. 1990 Decline of teak yield in northern Thailand: effects of logging on forest structure. *Biotropica* 22(2): 114-118.

- Selective harvest of teak reduces the volume of trees >60 cm dbh from 100.7 m^3/ha to 9.5 m^3/ha (91.2 m^3/ha).
- A study of a teak forest 25 years after logging showed good regeneration of teak but a lack of large trees, especially in the 40-45 cm dbh class, is most likely due to the harvest being too intense and greater than can be sustained by the natural productivity of the forest.
- In the study area 49 of 89 stumps/ha were less than 60 cm dbh class.
- Total stem volume in stand 152.1 m^3/ha (111.4 m^3/ha of teak).
- Volume removed in cut based on number and diameters of stumps estimated at 159.5 m^3/ha (89 stumps/ha).
- The average stump height in the area was 95 cm.
- Minimum dbh cutting limit for teak is 60 cm.
- Only 5 residual trees/ha had a dbh >60 cm.
- The annual dbh increment for teak in the study area was 1.61 cm.
- Therefore, another 14.25 years needed for the trees in the 35-40 cm dbh class to become marketable (i.e., total time from previous harvest about 40 years).

Ganzhorn, J.U., Ganzhorn, A.W., Abraham, J.P., Andriamanarivo, L. & Ramananjatovo, A. 1990 The impact of selective logging on forest structure and Tennec populations in western Madagascar. *Oecologia* 84(1): 126-133.

- Logging intensity 10 m^3/ha.

Gerwing, J.J., Johns, J.S. & Vidal, E. 1996 Reducing waste during logging and log processing: forest conservation in eastern Amazonia. *Unasylva* 47(187): 17-25.

- A close look at the growth of the region's (Para State) wood industry reveals a repeated pattern of the careless exploitation and degradation of forests near mill centres.
- Wood waste and increased canopy openings result in increased fire risk.
- Breaking this destructive pattern requires a shifting from forest mining to a system of forest management.
- Planned forest extracting included the following pre-harvesting activities: stand inventorying and mapping; vine cutting; road and skid trail planning and marking. In logging, directional felling and a skidder with winch (rather than bulldozer with no winch) were used.
- In the study found wood waste as logs felled and bucked but never skidded, and the needless destruction of young trees of commercial species.
- Mill waste also high through degradation of logs before processing and excessive lumber thickness due to excessive sawing variation.
- Waste could be greatly reduced by the adoption of straightforward management practices.
- Traditional timber extraction currently practiced can be thought of as unplanned forest mining that both wastes usable timber and damages the future productive capacity of the forest.
- The chain sawyers have little formal training in tree felling and no training in forest management or silviculture. Payment is based on production and not quality, thus, rapid sawing is better rewarded than careful sawing.
- Skidding occurs several days after felling and there is no real communication between the felling crew and the skidding crew. To find felled trees the bulldozer operators drive their tractors towards openings in the forest canopy. When a log is found it is skidded back to log landing, but not necessarily by retracing the path used to arrive at the log. The result of this unplanned searching and skidding is a criss-crossing network of skid trails, some of which lead to natural forest gaps in which no timber tree was felled.
- In three previously logged sites 6.6 m^3/ha of usable timber was felled but never skidded, which represents one tree per hectare or as much as 20% of the 30 m^3/ha of timber volume that is extracted from a typical hectare.
- The majority of the trees found were buried under the crowns of other felled trees or isolated from other timber trees.
- The above type of waste did not occur in the planning logging areas.
- Other waste was in high stumps (trees without buttresses), or not sawing the buttress off and then felling the tree (trees with buttresses).
- Improper sawing at the base of the tree so that the bole splits upwards from the base as it falls.
  · Bucking a tree too far from the top and leaving the usable bole with the crown.
- In conventional logging sites it was found that 0.41 m^3/tree was lost in the above four types of cutting errors. This is 7% of the harvestable volume of a tree or 2.3 m^3/ha.
- A study of 164 trees directionally felled by a trained chain sawyer showed 0.11 m^3 of waste per tree felled in felling and bucking operations or 1.7 m^3/ha less wastage.
- Combined with trees that are never found in skidding results in a saving of 8.3 m^3/ha which resulted from planned timber extraction and training the chain sawyer.
- In conventional logging 5-6 trees/ha are extracted, but an additional 200 trees/ha with more than 10-cm dbh are incidentally damaged.
- Vines in the region connect the canopy of a tree on average to six others.
- Also with uncontrolled felling the trees are often felled on each other, cause a major tangle which the bulldozer operator must push apart by using his blade and excessive tractor movement in the stand.
- Long lengths are generally skidded (i.e., bole is just topped) and skidding the logs back along twisting trails results in considerable residual tree damage and damage to the log itself.
- To reduce damage it is proposed that: vine cutting occur two years prior to logging; directional felling be used; planning of skid trail location; and use a tractor with a winch.
- In conventional logging 28.7 trees (dbh >10cm) were damaged per tree felled, compared to 20.5 trees per tree in the planned operation (46 more trees (dbh >10 cm) were undamaged in the planned harvesting area).
- In conventional skidding an additional 7.1 trees were damaged for each log skidded, compared to 4.4 trees per log skidded in the planned logging. This is equivalent to 16.2 fewer trees damaged per ha, for a total of 91 fewer trees damaged per hectare in the planned logging areas.
- Of the 91 potential trees - 57 would be severely damaged (i.e., topped or smashed) and of these, 11 trees (totally 2.7 m^3/ha) were of species with current commercial value.
- Processing yield at the mills in Paragominas were low also.
- Saw timber yield was 35% (low yield due to wood waste at various steps during log processing, inadequate log storage resulting in volume and quality losses, excessive storage period length (i.e., 15% of log volume was found to be affected by insect damage).

- Also log splitting (checking due to drying) affected 13% of the total sawable log volume.
- Outdated technology used in the sawmills (mean age 10 years) ??? result in a sawing loss of 3-5% due to sawing thickness variation.
- Improvement should raise conversion efficiency of veneer mills from 39% to 60% and for sawmills from 35% to 50%.
- Conventional logging gives 30 m^3/ha @ 35% lumber recovery or 10.5 m^3/ha of lumber, while planned logging and more efficient processing gives 38.3 m^3/ha @ 50% lumber recovery or 19.2 m^3/ha of lumber.

Gilmour, D.A. 1977 Logging and the environment, with particular reference to soil and stream protection in tropical rainforest situations. *In: Guidelines for watershed management*. Food and Agriculture Organization of the United Nations, Rome, Conservation Guide 1. p.223-235

- Ground skidding with a tractor without an arch causes unnecessary soil disturbance and gouging of skid trails, frequently turning them into well defined waterways which are difficult to drain - the use of an arch would assist in reducing this sort of damage.
- It is important that road and skid trail grades be kept as low as possible, because the erosion potential of surface runoff increases with velocity.
- Ensuring drainage of skid trails and roads is a self evident method of reducing erosion and stream sedimentation.
- Uphill skidding is preferable to downhill skidding in regard to erosion control.
- After logging the area should be inspected and roads and skid trails put "to bed".

Grace, K.T. & Adnan, A. 1996 Elephants: The Lumbering Giants. *ITTO, Tropical Forest Update* 6(3).

- Elephants are a low cost, low impact means of hauling logs in the forest.
- However no studies comparing the damage level caused by elephant and conventional machine-based logging appear to have been carried out, but some general observations can be made.
- When elephants are used, skid trails in the logging area are not required, greatly reducing the amount of mineral soil exposed.
- Elephants can also be used to float logs down shallow streams, reducing the need for access roads.
- They can however cause soil compaction over defined trails through the forest, although the area affected is much less than under conventional tractor logging.

Gray, J.A. 1997 Under pricing and overexploitation of tropical forests: forest pricing in the management, conservation and preservation of tropical forests. *Journal of Sustainable Forestry* 4(1/2): 75-97.

- Low forest revenues can result either from low forest fees, set at levels well below the value of the timber, or from low collection rates, the result of inefficient collection systems.
- Low forest fees, which mean that timber is under priced, encourage poor utilisation of timber in the forest and inefficiency in utilisation in processing industries.
- Economic incentives and better-designed forest revenue systems can contribute to and support improved forest management and administration. Higher prices and values of tropical timber would make improved forest management economically attractive.

Grieser-Johns, A. 1996 Bird population persistence in Sabahan logging concessions. *Biological Conservation* 75 (1): 3-10.

- Logging intensity in Sabah averages around 120 m^3/ha.
- Logging intensity in Sarawak averages around 90 m^3/ha.
- Logging intensity in Peninsular Malaysia averages around 52 m^3/ha.
- Levels of damage of the forest are correspondingly high.
- In the Ulu Segama Forest Reserve in south-east Sabah the logging intensity between 1970-1990 averaged 118 m^3/ha (range 73-166 m^3/ha) (Marsh and Greer 1992).
- In coupes logged during the late 1980s, tree losses during felling reached 62%, under conventional (tractor) logging techniques, and 80% under overhead cable techniques.
- Study emphasizes the importance of small refuge areas within logging concessions in assisting bird recolonization.

Grieser-Johns, A. 1997 *Studies on the effects of tropical forest management on biodiversity: a summary bibliography*. *FRR Technical Report Series No*. 2. 26pp.

- A review of the literature on the effects of forest management and logging on biodiversity in the tropical and sub-tropical regions by countries/regions.

Gullison, R.E. & Hardner, J.J. 1993 The effects of road design and harvesting intensity on forest damage caused by selective logging; empirical results and a simulation model from Bosque Chimanes, Bolivia. *Forest Ecology and Management* 59(1): 1-14.

- The value of previously logged forests for future timber production, and the contributions of these forests to the conservation of biodiversity, will depend to a large degree on how much damage is done to the forest during the initial log extraction.
- In the study area a 20-year first pass through the area is planned, with the hope that more species can be harvested in the second harvest since the volume of mahogany will be considerably lower (currently mahogany makes up 95% of the harvest).
- Study area was 602 ha, from which 74 commercial mahogany trees were extracted (= 0.12 trees/ha); the main road was 4993 m in length and 6.62 m wide; skid trails totalled 8523 m and 3.53 m wide.
- Area under roads was 6.31 ha or 1.05%.
- Felling gaps ranged from 100 m^2 to 1000 m^2, with the average size being 380 m^2, resulting a total felling area damaged of 2.81 ha or 0.47%.
- Secondary damage caused by roads was much greater than damage caused by felling of commercial trees, with the damage corridor being almost four times wider than the road itself (i.e., 24.69 m for main roads and 13.23 m for skid trails).
- Area of road secondary damage was 17.29 ha or 2.87% of the total area.
- Total damage in area directly under roads, secondary damage and gaps is 26.41 ha or 4.39% of the study site (3569 m^2/tree removed).
- Minimizing the amount of main road minimized the amount of damage.
- The roads built by the logging company caused 25.2% more damage than the best road system designed by the computer program (i.e., straight main road with skid trail running off of it).
- A computer model showed that damage to vegetation adjacent to skid trails and damage caused by tree felling became increasingly important components of overall forest damage as the density of harvested trees increased, and damage to the forest rapidly escalated with increased logging intensity.
- On the other hand more disturbance is necessary to get sufficient regeneration of mahogany.
- Through the design of roads and the control of harvest intensity, a forest manager can have a substantial impact on forest damage, re-entry time and post-harvest regeneration in logged forests.

Gullison, R.E., & Hardner, J.J. 1997 The percentage utilization of felled mahogany trees in the chimanes forest, Beni, Bolivia. *Journal of Tropical Forest Science* 10(1): 94-100.

- The study took place in the Bolivian lowlands. Two forest types in the Chimanes Forest contain significant quantities of mahogany (total volume 159-180 m^3/ha and 100 m^3/ha respectively).
- Harvesting is regulated through a minimum cutting diameter limit of 80cm, and the requirement that 10% of commercial sized trees should be left as seed trees.
- The processing efficiency at the mill is estimated as 60%.
- Wood waste was calculated including straight branches with a minimum diameter of 20cm and a minimum length of 1m.
- Quantities of residual branch wood are substantial, ranging from 0.85 m^3 to more than 16.3 m^3 per tree. In a few cases, the branch segments themselves exceeded the minimum cutting diameter of 80cm.
- The percentage utilisation of mahogany ranged from 49.2 to 90.5%, and decreased significantly with increasing diameter.
- Using an average diameter of 1.3m, the concessionaire extracts 14.48 m^3 of wood per tree felled, leaving 8.44 m^3 of branch wood behind.
- Stem cut-offs, buttresses and the stump usually account for 20.2% of the total tree volume.

Hall, J.S., Harris, D.J., Medjibe, V. & Ashton, P.M.S. (*in press*) The effects of selective logging on forest structure and tree species composition in a Central African forest: implications for management of conservation areas. *Forest Ecology and Management*.

- The forests of Central African enjoy world-wide recognition for their spectacular wildlife and also harbour an abundance of high quality timber. With mismanagement and the conversion of large tracts of West African forest to agricultural production, Central African forests are experiencing increased harvesting pressures. This is particularly true for species of African mahogany (*Entandrophragma* spp.).
- In the tri-nation region of Cameroon, Central African Republic, and Republic of Congo, a widely applied version of the Integrated Conservation and Development Model attributes the dual management objectives of biodiversity conservation and timber production to the same zones. Many conservationists working in the region believe that highly selective timber extraction is the best management scenario to meet these objectives. Conventional wisdom hold that if selective logging does not adequately regenerate *Entandrophragma* spp., loggers will quit the region after having mined the forest.
- A comparison between unlogged, 6-month and 18-year post-harvests forest stands indicates lasting effects of highly selective, high grade logging.

- While there was little difference in tree species composition and diversity between treatments, stem densities of both saplings and trees in unlogged forest were significantly higher than those in forest sampled 18 years after logging.
- Evidence suggests inadequate recruitment of *Entandrophragma cylindricum* and *E. utile*, the principal timber species, to justify continued timber extraction.
- Data indicate a significant shift in canopy disturbance. Nevertheless, an abundance of other top quality timber species remains after selective removal of African mahogany and these forests will remain attractive to loggers long after the elimination of *Entandrophragma* spp.
- A better approach to manage timber zones for timber production and conservation would be an adaptive management approach based on increased species selection and canopy disturbance. Zones targeting the conservation of closed forest obligate species should not be logged.

Hammond, D.S., van der Hout, P., Roderick, J.Z., Marshall, G., Evans, J. & Cassells, D.S. 2000 Benefits, bottlenecks and uncertainties in the pan tropical implementation of reduced impact logging techniques. *International Forestry Review* 2(1): 45-53.
- While most studies suggest that there is generally an overall net benefit in using RIL techniques, a number of uncertainties and potential bottlenecks remain.
- The use of RIL techniques will ultimately fail to produce the expected benefits when harvesting levels overshadow the gains made through careful planning. Harvesting intensities are highly sensitive to the spatial distribution of commercial stems and the ecological and economic implementations their distribution has for reducing damage at the expense of foregone timber.
- Stable supplies of currently marketed timber species will only be enhanced in stands where RIL techniques are employed if the resulting level of disturbance is consistent with the regeneration requirements of the target timber species.
- Benefits derived from a reduction in soil disturbance and erosion will vary depending on the prevailing background conditions. Differences in topographical, soil and hydrological conditions will alter the savings made by RIL when the costs of these environmental impacts are counted.
- The interaction between slope, soil and stem size will constrain the achievable environmental benefits without further technological and financial inputs.
- Damage associated with the type of machinery used to extract timber, not the way in which it is used, is limiting when conditions prevent the use of less destructive techniques.
- It is necessary to account for the varying cost of training and subsequent rise in wages. However, higher wages can be seen as a medium to long-term investment.
- The capital costs of equipment required for the implementation of RIL (such as databases, GPSs and data loggers) must be incorporated into the calculation of costs and benefits associated with better planning.
- If the costs of implementing RIL are at a level acceptable to the industry, then RIL will be widely adopted.
- Mechanisms to reduce the financial burden should be developed particularly where financial benefits are not certain.

Hamzah, Z. 1978 Some observations on the effects of mechanical logging on regeneration, soil and hydrological conditions in East Kalimantan. *BIOTROP Special Publication* 3: 73-78.
- On average the standing volume (dbh >50cm) is 115 m^3/ha (68 m^3/ha dipterocarps; 24 m^3/ha non-dipterocarps; 23 m^3/ha non-commercial).
- Based on cruise data an estimated exportable volume is 48.5 m^3/ha.
- Forestry Service in Indonesia accepts a waste of 30%.
- Using a waste rate of 30% the net extracted volume is 34 m^3/ha.
- In a review of logged over areas very few, if any, dipterocarp saw log sized trees, poles and saplings were found in the trafficked part of a logged-over forest.
- 42 m/ha of road to log an area and daylighting area can extend to 50 m from the centre-line of the road on both sides of the road.
- It is too optimistic to assume that trees of saw log size will mature 35 years after logging and that they will constitute the second crop in the following cutting cycle.

Harvey, **Brian & Brais, S.** 2002 Effects of mechanised careful logging on natural regeneration and vegetation competition in the south eastern Canadian Boreal Forest. *Canadian Journal of Forest Research* 32(4): 653 – 666.
- Careful logging regulations in Quebec restrict circulation of harvesting and forwarding or skidding machinery to evenly spaced, parallel trails, which creates a particular pattern of disturbed and relatively undisturbed zones in cutovers.
- A 7-year monitoring study was established to evaluate the effects of careful logging on vegetation development in the southern boreal forest of Quebec. A total of 255 sample plots (2 m2) were located

in seven cutovers in predominantly black spruce (*Picea mariana*) forests that were whole-tree "careful logged": 120 on fresh to moist silty clays or silty clay loams and 135 on dry to fresh loamy sands.
- Three microsites were sampled: skid trails and the edge and the centre of protection strips.
- A gradient of disturbance from the skid trail to centre of the protection strip was evident for finer textured sites.
- Careful logging resulted in high densities of black spruce and balsam fir (> 20 000 stems/ha each) in the protection strip.
- Survival of other understory species was also favoured in protection strips.
- Higher disturbance levels in skid trails favoured establishment of larch, raspberry and graminoids.
- Reduction of ericaceous cover occurred in skid trails on coarse-textured sites but was only temporary.
- Softwood stocking 7 years after harvest after harvest (based on 2-m^2 plots), ranged from 69 to 74% on sites.
- The pattern of vegetation development created by careful logging has important implications for silvicultural decisions and stand modelling.

Hawthorne, W.D. 1997 *Towards an improved logging system in Ghana: a fresh look at logging damage and forest regeneration (draft). FRR Technical Report Series*, No. 3. 43pp.
- a literature review of logging damage and tree dynamics relating directly to Ghana, and even Africa, would be very short, yet studies from other countries are frequently of dubious relevance
- it is an open question how far trends of logging damage, recovery and regeneration in one locality can be extrapolated to others
- ground-based logging systems (as widely use in the tropics) are used in Ghana for selective logging on a 40 year cycle
- within Ghana there was no good evidence that plant biodiversity would suffer as a consequence of logging, providing that careful logging measures are adopted
- In Ghana, a history of `bad' logging is strongly correlated with a history of `bad' record-keeping, thus making a historical review of logging impacts/damage unproductive.
- As data becomes available from permanent sample plots and growth and yield studies, the modelling of tropical forest dynamics is starting to become feasible.

Healey, J.R., Price, C. & Tay, J. 2000 The cost of carbon retention by reduced impact logging. *Forest Ecology and Management* 139: 237 – 255.
- Reduced-impact logging (RIL) is one means of reducing the carbon emissions held responsible for global warming.
- Comparable effects of RIL and conventional logging were studied in Sabah, Malaysia.
- RIL reduced the area logged within a tract by 44% and resulted in a 22% reduction in timber yield per logged hectare when compared to conventional logging.
- RIL resulted in less damage than conventional logging.
- RIL resulted in an 18% increase in costs per m3 logged as compared to conventional logging.
- Per m3 of timber logged RIL was beneficial without discounting, but had a net cost at a 2% discount rate and higher.
- The overall cost of RIL's carbon retention varied in both discount rate and level of analysis, from negative price to more than US$ 50 per megagram at a 10% discount rate. ▪ RIL appears most cost-effective on a per m3 logged basis at low discount rates.
- However, at commonly applied discount rates (4% and above) RIL's carbon price exceeds most published estimates for carbon prices.

Heinrich, R. 1995 *Environmental sound harvesting to sustain tropical forests*. IUFRO XX World Congress, Tampere, Finland, August 6-12, Congress Report, Volume II. p.436-446.
- Forest degradation and forest destruction are often caused by careless unplanned and uncontrolled harvesting of forest products in excess of their regenerative capacity.
- This is particularly the case of timber harvesting in the rain forests in the tropics.
- Increments of timber in plantations may be as high as 30 m^3/ha/year compared to 2-8 m^3/ha/year form a managed natural forest.
- Training of forest workers is very important from both forest sustainability and industrial accident points of view; poorly trained forest workers have more serious accidents than well-trained workers do.
- Poor felling and cross-cutting, as well as poor knowledge of log grading rules, also result in volume and value loss; experience with training programs to improve cross-cutting skills suggest that wood recovery can be improved by 20% or more, and that the value of logs increased by 10-50%.

Hendrison, J. 1989 *Damage-controlled logging in managed tropical rain forests in Suriname*. Wageningen Agricultural University, Netherlands. 204pp.

- A polycyclic silvicultural system on a 20-30 year felling cycle is most appropriate for rain forests in Suriname, than a monocyclic silvicultural system with a rotation age of 60-80 years.
- Soil recovery is a slow process and skid trails used 8 years previously were still found to be maximally compacted.
- Controlled logging was found to be more efficient than conventional logging.
- Felling productivity was more or less the same, even with more careful and directional felling, however, skidding production under the controlled system was twice that of conventional logging.
- Cornerstone is planning and 100% enumeration of harvestable commercial trees and marking all major terrain features on a large-scale map (e.g., 1:10000 or 1:5000).
- Field staff need to be trained in all parts of the job to allow job rotation - this give flexibility and makes the work more interesting for the workers.
- Felling intensity is restricted in Suriname to not exceed 30 m^3/ha, in order to maintain the ecological, conservation and protective functions of the forest.
- When tree location maps are not available the tractor operator has to find the logs by making trails through the forest.
- A large canopy opening may take a longer period to recover because succession starts at the pioneer phase, while a small gap may be closed rapidly by the crowns of trees surveying or recovering from the felling impact.
- Timber harvesting should not be an activity on its own but be integrated with silviculture in one forest management system.
- Shifting cultivation along forest roads has grown almost simultaneously with the road building program.
- Logging has become a capital-intensive operation, the cost of which has to be recovered by raising output.
- When felled trees are linked by lianas, a felled tree can easily damage neighbouring trees and may even uproot them. Large open spaces may appear in the forest vegetation as a result of the chain effect of falling trees (Fox 1968, Putz 1984).
- A felling intensity of 5-8 trees/ha is considered to be sustainable for most types of tropical forests (Boerboom and Wiersum 1983).
- The amount of damage done in this operation will depend on the proposed logging intensity, and the planned organization of the harvesting work.
- Poor work methods and techniques during felling and terrain transport lead to splitting and breaking of felled trees.
- Wood damage, involving serious loss of quality, can occur during positioning and collecting (bunching) of logs with the blade of a skidder.
- In addition, logs may deteriorate during storage in the forest and at roadside or river landing.
- In some western countries, control of stand damage is a management objective in harvesting systems.
- In selection felling every effort is made to keep the remaining stand in a healthy state, by carrying out each periodic harvest with the greatest care.
- Damage-controlled logging aims to use the technical and ecological potential of the forest without endangering its existence.
- direction felling is used to improve efficiency and to restrict damage to the remaining trees
- In past operations, creaming of the best commercial trees without replacement has led to selective forest depletion.
- In one system used (BSH) an incentive is given to exceed a certain production level - this in turn results in more damage to residual trees since efficiency and not stand protection is the goal (BSH is a type of semi-controlled logging, because no measures are taken to prevent or restrict logging damage).
- In the period 1957-70 the logging intensity was 8-10 m^3/ha.
- In the pre-logging survey an experienced crew can cover two units (each unit is 10 ha) within a day (100% tally of all commercial species of harvestable size (>35 cm dbh)).
- On average an efficient trail system should be limited to cover 5-8% of the area.
- Forests in the study had been logged previously at an VAC intensity of at least 6 m^3/ha.
- Controlled felling did not influence the number of damage trees within a gap (about 72% of the trees in a gap area were undamaged by felling (controlled and conventional)).
- However, the area of felling gaps was higher in the uncontrolled compartments by about 40% (had more and larger felling gaps).
- Skid trail area was 50% less in the controlled logging areas (5.4-7.3) vs. uncontrolled (conventional) (14.5 and 16.0%).
- Wood damage was substantially higher in the conventional logging area at 24.3-28.3 % vs. 6.1-8.5% in the controlled logging area.
- More trees with natural defects were felled in the conventional operations than in controlled harvesting.

- Skidding should be confined to permanent rail network, built trail on good, well drained ground, harvesting carried out during seasons when soil damage will not occur.
- Terrain transport has become the bottleneck in timber harvesting and often a large number of felled trees remain in the forest for months because of limited skidding capacity.
- CELOS silvicultural systems aim for a logging cycle of 25 years and a yield of 30 m^3/ha.
- This can be achieved within the limits of controllable logging damage, because controlled logging reduces the effect of logging intensity.
- 20-30 m^3/ha of veneer and saw logs appears to be the most likely yield possible, when corrected for defects, conversion losses, processability and marketability.
- The maximum slope for economic skidding and crawling should not exceed 25% and the bearing capacity of the soil should preferably not exceed strength class 3.
- With controlled logging the logging damage was reduced by 40% at a logging intensity of 20 m^3/ha, and skidding area was restricted to 5-7% compared to 14% in conventional logging.
- Controlled harvesting is less costly than conventional logging.
- Also, the study indicated that at an operational scale, damage-controlled logging is not necessarily more expensive than commercial logging focusing on efficiency only.
- The extra cost of planning is returned by improved operational efficiency.
- Also, logging intensity on the next cycle can more or less be maintained at the same level.

Hering, K.G. 1993 Naturnahe Waldwirtschaft im atlantischen Küstenregenwald Brasiliens. *Forstarchiev* 64. 284-290.

- This study was carried out in southern Brazil.
- Currently the study site is managed for commercial timber, palm hearts and honey.
- The purpose of this study was to enhance the production of these timber and non-timber forest products while ensuring positive returns from the forestland.
- Harvesting operations reduced the stand density from 851 to 645 trees/ha (basal area reduced from 48.5 to 29.2 m^2/ha), which is equal to a harvesting intensity of 24% of the stems or 40% of the basal area (including trees damaged during harvesting).
- Harvesting intensities of up to 25% of the basal area ensure sufficient regeneration of primary forest tree species.
- With an annual growth increment of 1.8%, a cutting cycle of 12 years at a harvesting intensity of 25% appears to be sustainable. The annual harvesting rate would equal 2.56 m^3/ha.
- A comparison of management scenarios for a forest area of 2,208 ha indicated that sustainable management practices result in a present value of US$ 2.2 million compared to US$ 5.6 million with timber exploitation.

Hernández-Diaz, J.C. & Delgado-Pacheco, M. 1996 Damage evaluation of the remaining standing trees in a timber yarding operation (case study). *In*: *Proceedings of Forest Operations for Sustainable Forestry, XX IUFRO, World Congress*, August 6-12, 1995. IUFRO S3.05-00 and CIFOR Publication. p.33-37.

- study of a small cable yarding operation in selective cutting in Mexico
- initial stand volume 163.1 m^3/ha (113 adult trees/ha)
- marked volume 65.3 m^3/ha (45.3 trees/ha marked)
- extracted volume 41.4 m^3/ha (45.3 trees/ha felled) (63% of marked volume utilized)
- average piece size 0.78 m^3
- of the residual commercial volume 4.6 m^3/ha had severe or medium damage (about 4.7%)

Hinrichs, A., Ulbricht, R., Sulistioadi, B., Ruslim, Y. Muchlis, I. & Hui Lang, D. 2002 Simple measures with substantial impact: implementing RIL in one forest concession in East Kalimantan. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- In 1998, the management of P.T. Limbang Ganeca/East Kalimantan and the Sustainable Forest Management Project (SFMP-gtz) launched a RIL pilot project.
- The private company was testing and implementing RIL under the several conditions: RIL should not lead to major additional investments (re-engineering of harvesting machinery and change in methods are not required); RIL should neither reduce productivity nor increase operational costs; RIL should reduce logging waste and RIL should be in line with government regulations and certification requirements.
- In 1999, a comparative study was conducted in five 1-hectare plots of two compartments.
- The effects of conventional logging (CL) vs. RIL were evaluated, with regard to damage, efficiency, productivity and costs.

- Implementation started in 2000 on a 2 350 ha annual cutting block with ongoing monitoring/evaluation by the company, SFMP-gtz and a joint implementation team from the Ministry of Forestry the company and SFMP-gtz.
- The net exploitation factor in the RIL plots was higher (85 percent) than that in the CL plots (81 percent).
- Efforts have been made to increase timber usage efficiently by cutting the buttresses and placing the undercut properly
- Stand openings following RIL were 29 percent lower than after CL.
- In particular, opening up by tractors was reduced drastically (by 65 percent).
- The damage caused by tractors usually delays natural regeneration.
- The large reduction indicates considerable environmental benefits and demonstrates that forest concessions adopting RIL can pass forest certification more easily.
- The residual stand damage due to felling was not particularly different between the two treatments (dbh of trees measured was 20 cm up).
- However, damage to the residual stand caused by skidding in CL was far greater. RIL caused 26 percent less overall damage to the residual stand.
- In particular, RIL reduced residual stand damage from skidding by 55 percent as compared to CL
- Logging waste was reduced by 20 percent, although the CL operators were also instructed to reduce waste.
- RIL reduces skidding productivity by 15 percent, volume skidded is therefore reduced to 25.5 ha/mth.
- Operational variable machinery costs are estimated to be reduced by between 5 to 15 percent.
- The variable tractor costs (especially maintenance and fuel costs) could be reduced by 5 to 15 percent, although additional tractor costs accrue due to the use of higher quality cables in RIL.
- Harvesting costs (including planning and operational cost up to roadside/log landings) were approximately US$1.00/m3 higher (at an exchange rate of US$1.00 = Rp 6 000).
- Additional overheads for human resource development, block inspection, team coordination and planning technologies still need to be considered.
- Increased operational costs were covered directly by the financial gains due to higher timber utilization (increased net exploitation factor of about 4 percent).

Hinrichs, A. & Ruslim, Y. 2001 Implementing RIL in Indonesia. *ITTO Tropical Forest Update* 11(2) : 6 – 7.
- Detailed damage assessments were carried out in five 1-ha plots within two 100-ha compartments, one of which was harvested using RIL and the other by conventional logging. ▪ Volume felled in all plots was 65m3/ha (11-12 trees /ha)▪ Opening up caused by skidding decreased by 66% with RIL, while overall opening up decreased by 29%. ▪ Stand damage caused by skidding decreased by 56% with RIL, while overall stand damage decreased by 28%.
- Logging waste was reduced by 20% under RIL

Holdsworth, **A. & Uhl, C.** 1996 Fire and Amazonian selectively logged rain forest and the potential for fire reduction. *Ecological Applications*:7 (2): 713 – 725.
- Approximately 8000 km^2 of Brazilian Amazon forest are selectively logged each year. Although virgin forest in eastern Amazonia is generally immune to fire, selectively logged forests are susceptible to fire.
- In eastern Amazonia permanent plot studies, forest fuel moisture measurements, and hemispheric canopy photographs were used to study the impacts of fire on a selectively logged forest, the microclimatic conditions that foster forest fires, and the measures that loggers might take to reduce fire incidence.
- Significant tree mortality followed a typical ground fire in a selectively logged forest.
- Forty-four percent of all trees ≥ 10 cm in diameter at breast height died in a burned plot while only 3% died in an unburned plot.
- In large logging gaps the density of regenerating pioneer species increased by >60% in burned plots 15 months after the fire, while it decreased by >40% in unburned plots.
- The rate of fuel drying in selectively logged forest was influenced by photon flux density (PFD), time since logging, and logging techniques. There was a significant negative correlation between PFD and the number of days fuel sticks required to reach the point where fire could spread. In a recently logged forest, large logging gaps (>700m^2) reached fire susceptibility after 6 days and medium sized logging gaps (≈200 – 700m^2) reached fires susceptibility after 15 days.
- Fire susceptibility declines over time as logging gaps become densely packed with saplings;
- Fuel moisture conditions in large gaps of forest selectively logged 4 years earlier were similar to those found in virgin forests, thus reducing the likelihood of fire.
- Careful logging can also reduce the likelihood of fire. Special low-impact logging techniques remove the same amount of timber as do the more typical high impact logging techniques, but fire is

significantly less likely because the more careful operation avoids the creation of large logging gaps, the most fire susceptible areas.

Holdsworth, A.R. & Uhl, C. 1997 Fire in Amazonian selectively logged rain forest and the potential for fire reduction. *Ecological Applications* 7(2): 713-725.
- The study area was located near Paragominas in the eastern Amazon, Brazil.
- Low impact logging reduced the mean size of canopy gaps by 53% relative to conventional logging.
- Fire reduces the potential value of the forest, but by reducing the size of logging gaps low impact logging techniques can reduce the risk of fire.
- An average extraction intensity for the Paragominas region is 30-40 m^3/ha with a cutting cycle of 30-50 years.
- Using low impact logging techniques, 50 US$/ha are required to carefully plan and execute logging operations.
- According to Barreto *et al.1998* the additional costs of low impact logging would be completely recovered by the additional benefits.

Holmes, **T., Blate, G., Zweede, J., Pereira Jr., R., Barreto, P., Boltz, F. & Bauch, R.** 2002 Financial and ecological indicators of reduced impact logging performance in the eastern Amazon. *Forest Ecology and Management* 163: 93 – 110.
- A comparison of costs and revenues was made for typical RIL and CL operations in the eastern Amazon.
- An economic engineering approach was used to estimate standardised productivity and cost parameters.
- Detailed data on productivity, harvest volume, wasted wood and damage to the residual stand were collected from operational scale harvest blocks.
- Productivity and cost data were also collected using surveys of forest products firms.
- RIL was less costly, and more profitable, than CL under the conditions observed at the eastern Amazon study site.
- Full cost accounting methods were introduced to capture the direct and indirect costs associated with wasted wood.
- The impact of wasted wood on effective stumpage price provided the largest gain to RIL.
- Large gains attributable to RIL technology were also observed in skidding and log deck productivity.
- In addition, investment in RIL yielded an “environmental dividend” in terms of reduced damage to trees in the residual stand and reduction of the amount of ground area disturbed by heavy machinery.

Holmes, T.P., Boltz, F. & Carter, D.R. 2002 Financial indicators of reduced impact logging performance in Brazil: case study comparisons. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- Indicators of financial performance for three case studies in the Brazilian Amazon are compared.
- Case study results were disaggregated into common measures of productivity, cost and profitability.
- The Case Studies used were 1. Agrosete: The RIL-CL comparison was conducted on private forestland of Fazenda Agrosete, approximately 20 km southeast of Paragominas, Pará, Brazil. RIL was conducted on a 105-ha plot and CL on an adjacent 75-ha plot. 2. Cauaxi: Research was conducted on private forestland of the CIKEL timber company of Fazenda Cauaxi, some 120 km southwest of Paragominas, Brazil. 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 on an adjacent 100-ha plot. 3. Itacoatiara: The study examined private forestland of Mil Madeireira Itacoatiara S.A., a Brazilian subsidiary of Precious Woods, Ltd., which is located 227 km east of Manaus. Efficiency and environmental impact studies were conducted in two adjacent 10-ha cutting blocks.
- RIL investments in inventory, planning, vine cutting and infrastructure development up to a year before logging increases the proportional cost of pre-harvest operations
- At Fazenda Cauaxi, CL operations wasted 4.08m3/ha and RIL operations wasted 1.32m3/ha.
- At Fazenda Agrosete, CL (RIL) operations wasted 8.83m3/ha (0.40m3/ha) in the forest.▪ At Mil Madeireira Itacoatiara, CL (RIL) operations wasted 2.99m3/ha (1.31m3/ha)▪ CL sawyers were 10 to 22 percent more productive in volume produced per hour (m^3/hr) than comparable RIL-felling teams.
- Skidding operations are more productive under RIL.
- RIL utilizing rubber-tyre skidders increased productivity by 41 to 49 percent over CL bulldozer operations.
- 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.
- RIL training costs comprise 1 to 18 percent of total harvest cost for CL and RIL operations.
- RIL direct costs[16] (in US$/m3) ranged from 3 percent lower to 34 percent higher than CL direct costs.
- When direct and indirect waste costs are accounted for, RIL net revenues are 18 percent to 35 percent greater than CL net revenues

Howlett, B.E. & Davidson, D.W. *(in press)* Effects of seed availability, site conditions, and herbivory on pioneer recruitment after logging in Sabah, Malaysia. *Forest Ecology and Management.*
- In a recently logged forest, the seed sources and seedling establishment between conventional logging (CL) and reduced impact logging (RIL) and between two soil disturbance classes.
- More pioneer seedlings established on RIL than on CL plots, but survival of planted seedlings was lower under RIL, due to denser canopy cover.

Hutchinson, I.D. 1987a Improvement thinning in natural tropical forests: aspects and institutionalization. *In*: Mergen, F. and J.R. Vincent (eds.). *Natural Management of Tropical Moist Forests - Silvicultural and Management Prospects of Sustained Utilization*. Yale University, School of Forestry and Environmental Studies, New Haven, Connecticut. p.113-133.
- From 1974-1980 selective logging in Sarawak MDF extracted an average of 5-15 trees/ha (10-50 m^3/ha).
- With improvement thinning could have a polycyclic system with 60-year rotation and 30 year cutting cycle.
- In MDF forest in Malaysia, mean annual dbh increment of trees >10 cm dbh in control (all trees) was 0.22-0.34 cm/year, with overstory removal 0.37-0.44 cm/year, and with liberation thinning 0.45-0.56 cm/year (in this case if only reserved trees measured 0.77-0.99 cm/year).

Hutchinson, I.D. 1987b The management of humid tropical forest to produce wood. *In*: *Proceedings of Management of the Forests of Tropical America: Prospects and Technologies*, San Jan, Puerto Rico, September 22-27, 1986. USDA, Forest Service, Southern Forest Experiment Station. 121-155.
- Report gives the same logging intensity as in the previous article.
- The study showed that the incidence of injury per wood quality group did not differ significantly; i.e., loggers disregard the protection of standing stems of desirable species.
- Only 15 desirable stems/ha were recorded as being both of potentially commercial log grade and free from injury.
- Incidence of injury can be reduced by regular inspections and direction of operations by trained and experienced staff, and by post-logging inspection and enumeration.
- Selective logging eliminated 20% of the total number of stems that existed in the virgin forest, snapped the trunks of 5% and injured more than 66% of all stems >= 10 cm dbh.
- Improvement thinning after logging is necessary to improve the quality of the stand, otherwise it just degrades with each cutting cycle; e.g., 60% of the basal area per hectare of surviving trees with fully illuminated crowns comprised stems with visible decay, while 20% were recorded as being totally decayed.
- Without an improvement cut a significant component of the growth will be on unmerchantable trees.
- 40% of medium-sized trees were damaged by selective logging, thus jeopardizing the yield in the second cut.
- The incidence of total destruction of stems by selective logging falls most heavily on the small dbh classes.
- A minimum felling limit is needed to limit the intensity of the logging operations; this however needs to be complemented by improvement thinning.

Inglis, C.J., Sutton, G. & Lawson, G.J. 1997 Research and monitoring for sustainable forest management in North-west Guyana. *In*: *Proceedings of the FAO/IUFRO Satellite Meeting held in conjunction with the IUFRO XX World Congress, Tampere, Finland, 4-5 August, 1995, Research on Environmentally Sound Forest Practices to Sustain Tropical Forests*. Food and Agriculture Organization of the United Nations. p.27-36.
- BCL sets the minimum dbh for felling at 50-60 cm for the plywood mill.
- There are on average 7 trees/ha which fulfil the species, size and quality requirements for the mill and in fact only 5 trees/ha are being felled (average tree size is 3 m^3 = 15 m^3/ha).
- This is lower than in north-eastern Brazil where 6 trees/ha (38 m^3/ha) are harvested (Verissimo et al. 1992).
- For every 6 trees logged a further 21 were either pushed or pulled over or were snapped (1 bent, 17 pushed over, 4 crown snapped, 4 severe crown damage).
- Of the original 227 trees/ha (dbh >20 cm, 183 were not felled and had no logging damage.

- A need for evaluation of the effectiveness of pre-logging climber cutting.
- The CELOS system has partly guided the logging operations at BCL.

ISTF 1995 IMAZON logging improvement Note. *International Society of Tropical Foresters News* 16(1): 1,10.

- RIL with vines cut 18 months prior to logging.
- Directional felling made 85% of the felled trees easier to skid; about 40% were naturally in a good position, relative to the skid trail.
- Improved skidding operations resulted in less forest damage, less timber extraction time and lower extraction cost, than in the conventionally logged area.
- RIL looked much better, skid trails had good regeneration and canopy cover, the openings looked very similar to natural tree fall gaps.
- Vine cutting, directional felling and removal of buttresses clearly helped reduce damage and increased skidding efficiency.
- RIL stand suffered one-third less damage than the conventionally logged stand.
- The potential impact of an industry conversion to RIL is enormous.
- Adoption of RIL throughout the tropics would result in more efficient use of production forests that in turn would reduce pressure on primary forests.
- IMAZON results suggest costs may be reduced by one-third.

ITTC 1990 *The promotion of sustainable forest management: a case study in Sarawak, Malaysia*. Report by the ITTC Mission, Earl of Cranbrook (ed.) ITTC, Denpasar, Indonesia. 208pp.

- Prospective timber yield - Cutover Hill Mixed Forest (harvesting to the minimum dbh and assuming reduced impact logging):

Diameter classes	**60+ cm**		**45+ cm**		**30+ cm**	
Wood quality group[1]	1	1-3	1	1-3	1	1-3
Aver. residual crop						
- number/ha	0.9	1.0	6.7	8.3	13.1	17.0
- m^3/ha	3.4	3.8	15.4	18.8	22.0	27.8
Predicted harvestable volume by cutting cycles, m^3/ha						
25 years						
- untreated	8.6	10.1	27.4	34.8	41.3	45.6
- treated	18.5	22.6	32.6	41.9	54.2	69.9
30 years						
- untreated	14.3	17.6	29.3	37.4	45.2	49.1
- treated	23.4	29.2	43.0	55.4	60.7	78.3
35 years					Growth data incomplete	
- untreated	20.0	25.1	32.0	42.5		
- treated	28.3	35.8	53.4	68.9		
40 years						
- untreated	25.7	32.6	37.7	47.6		
- treated	33.2	42.4	63.8	82.4		
45 years						
- untreated	31.4	40.1	43.4	55.1		
- treated	38.1	49.0	74.2	95.9		
50 years						
- untreated	37.0	47.6	49.0	62.6		
- treated	43.0	55.4	84.8	109.2		

[1]Wood quality group 1 contains 179 timber tree species (5% of tree flora), while group 1-3 contains 785 tree species (23% of tree flora)

- It is seen that if the harvest were limited to trees of 60 cm dbh or more and to the choice no. 1 group, long cutting cycles (45-50 years) would be necessary to attain the present harvest of 38 m^3/ha.
- More realistic would appear a minimum dbh of 45 cm with species groups 1-3, permitting a 35 year cutting cycle.

- Indicated cutting cycles for hill forests (to produce a minimum 38 m^3/ha):

Minimum dbh, cm	Species group	Indicated cycle, years	
		Untreated	Liberated
60	1	50	45
45	1	40	30
30	1	25	15
60	1-3	45	40
45	1-3	35	25
30	1-3	20	10

- The above yields can never be attained by continuing present practice, which is damaging to the environment and the residual stand.
- The practices of the labour force in the forest directly cause much of the damage; practically no formal training for fellers or tractor and skidder drivers (experience is passed from one to the other). It is hardly surprising, therefore, that little attention is paid by the fellers to limiting damage to the residual stems or by skidders to this or other effects on the environment.
- Tractor and skidder operators are paid piece rates by most companies, and fellers apparently by all companies. The emphasis is on output and not on the minimization of damage.
- Safety standards are usually of a low standard.
- These weaknesses are exacerbated by inadequate staffing of the Forest Department and the consequent inability to exercise the degree of supervision required.

ITTO 1992a ITTO guidelines for the sustainable management of natural tropical forests. *International Timber Trade Organization, Policy Development Series* 1. 18pp.
- "To encourage the development of national policies aimed at sustainable utilization and conservation of tropical forests and their genetic resources, and a maintaining the ecological balance in the regions concerned."
- Principle 12: Proper planning, at national, forest management unit and operational levels reduces economic and environmental costs and is therefore an essential component of long-term sustainable forest management
- Possible action 13: The Annual Allowable Cut (AAC) should be set conservatively in the case of absence of reliable data on the regeneration and growth dynamics of tree species, especially with regard to diameter increment and response to the effect of logging on trees and soils. This applies both to tree species which, under current market conditions, are desirable or which have the potential to become commercially attractive in the future, recognizing that domestic and world markets for forest produce are under very dynamic development. In practice, this will often mean conservative setting of rotation length, felling cycle and girth limits. As and when permanent sample plots begin to yield more reliable information about dynamics of desirable species, a reassessment of AAC should be considered.
    - Possible action 15: Management inventory and mapping should be carried out
    - Possible action 16: Preparation of working plans
    - Principle 21: Harvesting operations should fit into the silvicultural concept, and may, if they are well planned and executed, help to provide conditions for increased increment and for successful regeneration. Efficiency and sustainability of forest management depend to a large extent on the quality of harvesting operations. Inadequately executed harvesting operations can have far-reaching negative impacts on the environment, such as erosion, pollution, habitat disruption and reduction of biological diversity, and may jeopardize the implementation of the silvicultural concept
    - Principle 22: Pre-harvesting prescriptions are important to minimize logging damage to the residual stand, to reduce health risks for logging personnel and to attune harvesting with the silvicultural concept
    - Possible action 19: To draw up detailed prescriptions, including measures such as climber cutting, marking of trees to be felled and/or residuals to be retained and indications of extraction direction and felling direction
    - Principle 23: Planning, location, design and construction of roads, bridges, causeways and fords should be done so as to minimize environmental damage
    - Principle 24: Extraction frequently involves the use of heavy machinery and, therefore, precautions must be taken to avoid damage
    - Principle 25: Post-harvest operations are necessary to assess logging damage, the state of forest regeneration, the need for releasing and other silvicultural operations to assure the future timber crop

- Appendix 3 (Roads and Harvesting) list considerations important on grounds of efficiency and to minimize environmental damage

ITTO 1992b Criteria for the measurement of sustainable tropical forest management. *International Timber Trade Organization, Policy Development Series* No. 3. 5pp.
- Part of the process to achieve ITTO's Target 2000 to ensure that all trade in tropical timber is sourced from sustainably managed forests by the year 2000.
- Sustainable forest management is the process of managing permanent forest land to achieve one or more clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment.

ITTO 1993a ITTO guidelines for the establishment and sustainable management of planted tropical forests. *International Tropical Timber Organization, Policy Development Series* No. 4. 38pp.
- Plantations will have a major role in fulfilling societal fibre requirements and to reduce pressure on natural forests.
- On the other hand, it would be wrong to assume that planted forests could substitute for natural forests and replace them as source of raw materials and environmental and social benefits. Such assumptions could lead to natural tropical forests being cleared to provide sites for industrial forest plantations which promise to produce much higher volumes of timber per unit area. However, major social conflicts may also arise from industrial plantations displacing existing landholders and disrupting prevailing patterns of land-use. Possible detrimental environmental and ecological effects of large-scale introductions of exotic tree species are also emerging as major concerns and policy issues in some tropical countries and amongst the international community.
- Actions recommended have a lot to do with BMPs and management and operational planning at all phases.
- Links logging operations directly in with silviculture.

ITTO 1993b ITTO guidelines on the conservation of biological diversity in tropical production forests. *International Tropical Timber Organization, Policy Development Series* No. 5. 18pp.
- Recommended action 11 - In forest areas of recognized importance for biodiversity conservation incorporate consideration of the effects of rotation length, felling cycles, girth limits and size of the annual area cut-over in deciding the allocation of the AAC.
- Recommended action 12 - when determining yield allocations and rotation lengths for particular management units, plan logging operations so that a mosaic of recently logged and old growth forests are maintained over time.
- Recommended action 16 - reduce individual gap size as far as possible, unless specifically required for the regeneration of key species. Avoid creating very large gaps that equate to areas of local clear felling.
- Recommended action 17 - minimize machinery and felling damage to the residual stand, undergrowth and soil.

ITTO 1996 Reduced impact, increased cost? *ITTO, Tropical Forest Update* 6(3): 10-12.
- A certain level of RIL can be achieved simply through careful planning, scheduling and control of logging operations.
- Cost of implement RIL in Malaysia 2.05 USD/m3 or 82 USD/ha (does not included additional cost of pre-logging inventory or training of felling crews and supervisors).
- Benefits assumed to be reduced skid trails from 250 m/ha to 200 m/ha (conservation reduction) (saving = 0.50 USD/m3 @ 393.70 USD/km of skid trail).
- 20% increase in skidding productivity results in a decrease from 393.70 USD/ha (9.84 USD/m3) to 314.96 USD/ha (7.87 USD/m3) = 1.97 USD/m3.
- RIL cost = 2.05 USD/m3 with a logging cost saving of 2.47 USD/m3 or 0.42 USD/m3.
- In addition to saving in logging costs there would be a substantial long term increase in timber yield.
- A reduction in logging damage from 20 to 15 trees/ha would result in a saving of 7.5 m3/ha (5 trees @ an average 1.5 m3/tree) of residual wood volume. Additional growth on these trees of 10 m3/ha over a 25 year periods could be expected, of which about 70% would be commercially recoverable timber.
- The overall additional wood fibre would thus be 14.5 m3/ha after 25 years, which could work out to 1184 USD/ha more revenue for the logger on the next harvest.
- One of the most significant benefits of RIL is the increase in value of the next harvest, but this is hardly likely to impress the holders of short-term concession rights who, above all, are the ones who must be convinced that RIL is in their best interests.
- Also need to implement training programs, which are mainly lacking in developing countries.

- Also have to deal with concession system, the performance of regulatory bodies, the expectations of society and the willingness of outside players to pay for various products and services from the forest.

Ivo, W.M., Ferreira, S., Biot, Y. & Ross, S. 1996 Nutrients in soil solution following selective logging of a humid tropical `terre firme' forest north of Manaus, Brazil. *Environmental Geochemistry and Health* 18(2): 69-75.
- Selective logging removed 35 m^3/ha of wood.

Jabil, M. 1983 Problems and prospects in tropical rainforest management for sustained yield. *Malaysia Forester* 46(4): 398-408.
- With the apparent failure of forest management in most tropical countries, there has been a growing tendency to question the validity and practicality of the concept of sustained yield in tropical rainforest management.
- The resultant controversy has been heightened by the successful introduction of fast-growing species in recent years in some tropical countries.
- This has led to the naive conclusion that the solution of the problems in tropical rainforest management lies in abandoning the natural forest.
- While the need for plantations cannot be denied, particularly in meeting long-term wood supply objectives, sustained yield management of the natural forest is imperative in most tropical countries.
- The successful practice of tropical rainforest management for sustained yield requires not only technical expertise and appropriate technologies but also careful planning and implementation.

Jackson, **S.M., Frederickson, T.S. & Malcolm, J.R.** 2002 Area disturbed and residual stand damage following logging in a Bolivian tropical forest. *Forest Ecology and Management* 166 : 271 – 283.
- The area disturbed and damage to the residual stand caused by planned diameter-limit logging was assessed in a tropical humid forest of Bolivia and compared with disturbance and damage reported in other studies in the neotropics with similar harvesting intensities.
- The forest was logged by a private company under a government concession.
- The harvest incorporated many reduced impact logging practices including pre-harvest tree inventories, planned placement of roads and skid trails, vine cutting, and directional felling.
- A total density of 4.35 trees/ha and 12.1 m^3/ha of wood were harvested.
- It was estimated that logging disturbed 45.8% of the stand including 25% ground area disturbance in the form of skid trails, logging roads, and log landings and an additional 25% in canopy openings due to tree felling.
- On average, 44 trees were damaged for every tree extracted including 22 trees killed or severely damaged, 6 of them commercial species. The most common types of damage included uprooted stems, stem wounds to the cambial layer, and bark scrapes.
- Road width was found to be a significant factor determining the number of trees damaged along logging roads but not along skid trails.
- Damage to trees sustained along skid trails was found to be significantly less than the damage incurred along logging roads.
- Residual damage in felling gaps was positively related to the diameter-at-breast height of the harvested trees.
- Comparisons with other planned operations revealed a higher percent ground area disturbed and a greater felling gap area per tree extracted.
- Higher ground area disturbance was mostly due to the greater area in skid trails, many of which appeared to be unnecessary.
- Larger felling gap sizes appeared to be at least partially attributed to the larger size of trees harvested relative to those in other forests.
- The results of this study suggest that reduced impact logging practices may also need to be accompanied by close supervision of field personnel, monetary incentives and/or disincentives to loggers, and post-logging site inspections to be implemented properly.

Johns, A.D. 1988 Effects of "selective" timber extraction on rain forest structure and composition and some consequences for frugivores and folivores. *Biotropica* 20(1): 31-37.
- Mechanized logging using heavy bulldozers and highlead yarding.
- In a West Malaysian dipterocarp forest the mechanized extraction of 3.3% (18 trees/ha) of trees (>=30 cm dbh) destroyed 50.9% (3.3% timber trees/4.8% destroyed during road building/3.6% destroyed when building landings and spar tree sites/39.2% destroyed during felling operation and log dragging) of the trees and damage was spread equally among all tree taxa and all size classes.
  · Of the 49.1% remaining trees 6.0% were standing but damaged.
- 18.3 stems/ha of marketable timber (24 m^2/ha) were extracted with minimum girths of 145-192 cm (46-61 cm dbh depending on species).

- Since only 3.3% of the stems were removed with 50.1% destroyed the term selective logging does not apply.

Johns, A.D. 1991 Responses of Amazonian rain forest birds to habitat modification. *Journal of Tropical Ecology* 7(4): 417-437.
· Study of terre firme rain forest in Amazonas State.
  · Logged during 1975-85 with a logging intensity of 3-5 trees/ha (main tree cut *Cedrelinga cateniformis*).
  · Damage was considerable at the time due mainly to careless citing of skid roads.
  · However, the forest had since regenerated over 11 years to a basal area of at least 15 m^2/ha, compared to 35 m^2/ha in unlogged forest.

Johns, A.D. 1992 Species conservation in managed tropical forests. *In*: Whitmore, T.C. and J.A. Sayer (eds.), *Tropical Deforestation and Species Extinction*. IUCN, Chapman and Hall, London. P.15-50.
- Logging is most often controlled by entrepreneurs, to whom short-term profits are of prime importance, rather than by foresters, whose duty is to the long-term maintenance of the resource.
- A logging contractor, or a contractor with a short-term lease, will be concerned only with a single cut and will not be motivated to minimize environmental damage.
- Lack of financial interest in the future crop is probably the main reason for the excessive damage levels typical of short-term extraction operations.
- Commercial logging in tropical rain forests can take a number of forms, almost all of which involve the removal of selected trees rather than the clear-felling of whole stands. The only exceptions are three operations (Columbia, Papua New Guinea, Sabah) where forests are clear-felled for wood chips.
- In Amazonia, up to 140 species may be logged in the eastern forests accessible both to local markets and to the populated regions of southern Brazil (Uhl and Viera, 1989), whereas a few as two or three species may be cut in the isolated western regions (Johns 1988a).
- Harvesting intensity in tropical forests varies considerably from 1 to 72 trees/hectare depending on the forest type and country.
- Malaysian dipterocarp forest up to 72 trees/ha felled (extremes that result in total destruction of the forest canopy), with an average being 14 trees/ha.
- Most Amazonian terra firme forests yield only 3-5 trees/ha.
- This equal to level 2 harvesting at about 10-15 m^3/ha/cycle (Braz and d'Oliviera 1995).
- Level 3 harvesting will be more intensive and remove 30-40 m^3/ha/cycle (Braz and d'Oliviera 1995).\
- Some African forests as low as 1.1 trees/ha.
- The number of species used is increasing in many parts of the world.
- In the 80's 8.4-13.5 m^3/ha for neotropical and African forests (Freezailah 1984).
- In Asian dipterocarp forests generally more than 50 m^3/ha, and in Sabah up to 110 m^3/ha.
- Monocyclic systems - remove all merchantable trees in a single operation - come back in 70 years time.
- Polycyclic systems - lower initial felling intensity, designed to limit damage to advance regeneration of commercial species which become a viable second crop after only 20-30 years.
- An emergent tree of >2.5 m girth will destroy around 0.02 ha on falling (Dawkins 1959).
- Main access roads through the forest have ROW widths of 20-30 m wide to allow sun to reach the ground and thus dry up the road faster.
- These roads and their landing areas occupy from 6-20% of the forest (Hamzah 1978, Malvas 1987).
- Skid roads in the cut area average 4 m in width and can be 270 m/ha.
- Kartawinata (1978) estimates that 30-40% of the logged forest in Indonesia may be left bare of vegetation as a result of roading and dragging activities.
- Some kind of damage to 40% of the residual trees is common (Abdulhadi et al. 1981).
- Post harvest wind throw can also be increased due to the uneven nature of the canopy after logging and increased wind turbulence.
- A study in Sarawak (Marn and Jonkers 1981, Marn 1982) showed that felling trees in the direction which caused least damage, careful citing of skid roads and the restriction of tractors to them reduced damage levels by half without increasing cost.
- Results from Queensland in fact suggest that logging reverses a natural loss of diversity that occurs as a forest matures after disturbance and pioneer species die out (Nicholson et al. 1988). However, logged forests may not always regain all species lost during logging and their species composition may be somewhat different.
- It is generally recognized that damage levels attached to current logging operations, particularly intensive logging operations, are unnecessarily high.
- Experimental operations in Sarawak and Sabah have shown that the levels of incidental damage, even under intensive harvesting, can be reduced by as much as half (Marn 1982, Malvas 1987).
- There is an optimum canopy gap size at which the regeneration of timber trees may be affected. Larger gaps caused by felling too many adjacent trees commonly stimulate the growth of commercially

useless pioneer tree species, woody climbers and shrubs, which can be a bane to future management operations.
- In most tropical forests, the most effective form of forest management is undoubtedly protection and encouragement of advanced growth in optimally sized gaps created during logging, with planting of
- gaps where no advanced growth exists.

Johns, J.S., Barreto, P. & Uhl, C. 1996 Logging damage during planned and unplanned logging operations in the eastern Amazon. *Forest Ecology and Management* 89: 59-77
- For each commercial tree felled, unplanned logging damaged 16 more trees >= 10 cm dbh and affected a ground area that was 100 m^2 greater than in planned operations.
- Unplanned vs. planned (severe crown damage 7.4 vs. 4.5 trees/trees felled) (trees smashed to the ground 7.2 vs. 4.9 trees/trees felled).
- More trees experienced moderate or severe damage along unplanned skid trails than along planned skidder skid trails. These differences are particularly pronounced in the bole damage categories (7.9 trees >10 cm dbh smashed and 5.3 trees >10 cm dbh with moderate bole damage per 100 m of unplanned bulldozer skid trails vs. 5.3 trees smashed and 2.2 trees with moderate bole damage per 100 m of planned skidder skid trails).
- Unplanned felling damaged almost 2x as many trees per hectare as planned felling (124 vs. 64).
- Damage to individual trees was reduced in the planned logging operation by cutting vines 2 years prior to logging and by implementing directional felling.
- Estimate the profit margins for companies doing planned fellings will increase.
- Planned logging costs offset by benefits from reduced machine operating hours and labour per m^3 of timber extracted and less waste.
- More than 80 trees per hectare were spared damage with planned logging.
- With planned logging damages can be reduced by 25-33% and the logging can be done on a 30-40 year cycle.
- With a planned harvest, subsequent cuts should yield more or less the same volume as the first harvest, otherwise 75-100 years would be required to get the same logging intensity.
- Presently logging in Brazil Amazon is done carelessly, and even though only a few trees are removed the forest is left in a highly degraded state.
- Logging intensity in planned logging 37 m^3/ha (=4.5 trees/ha >52 cm dbh).
- Logging intensity in unplanned logging 30 m^3/ha (=5.6 trees/ha >45 cm dbh).
- The total ground area affected by the planned skidder operation was 1503 m^2/ha, planned bulldozer operation 1706 m^2/ha, and unplanned bulldozer operation 2276 m^2/ha.
- The biggest differences are found in manoeuvring the machine in the bole area (254 m^2/ha unplanned bulldozer vs. 23 m^2/ha planned bulldozer vs. 45 m^2/ha planned skidder), constructing log landings (153 m^2/ha unplanned vs. 61 m^2/ha planned) and constructing roads (336 m^2/ha unplanned vs. 203 m^2/ha planned).
- Measures to reduce damage .
- VINE CUTTING two years prior to cutting - vines cause damage when trees are felled (i.e., tree felled pulls over trees linked or at least breaks part or most of crown) and during road build with the bulldozer.
- Average gap size in planned harvesting 166 m^2 while in unplanned logging 355 m^2 (the average gap size for natural tree falls in the region is about 200 m^2).
- Almost as cost effective as directional felling.
- DIRECTIONAL FELLING results in less damage to residuals and less tangling of felled trees, which in turn results in less tractor movement in the stand to untangle the logs
- The most cost effective mitigating technique.
- USE OF SKIDDERS results in less damage because narrower (3 m vs. 3.4-3.6 m in study) and less disruptive to the soil surface.
- A skidder with a winch can also cut down on the amount of vehicle movement in the stand.
- However, if the bulldozer has a winch there is less area traffic in planned logging since the skidder requires a larger area to turn around (i.e., bulldozer can do a 360 degree turn).
- My comment - this can be fixed by fewer turn-arounds and turning into the corridor from which the log(s) are being winched.
- PLANNING AND LAYOUT OF SKID TRAILS with the trails in a herring bone fashion with main and secondary trails reduced the amount of trail in the stand.
- In unplanned logging the bulldozer operator basically just wandered through the forest.
- Also skidding shorter pieces results in less damage to residual trees through rubbing.
- LANDING CONSTRUCTION - in planned logging the amount of timber is known and the landing the wood will be skidded to is known. Therefore, the landing can be made to the size required, otherwise they are generally made too large.
- With planned harvesting the second harvesting intensity will more or less be the same as the first (38 m^3/ha), while with unplanned harvesting it is estimated to be 17 m^3/ha, on a 30 year logging cycle.

- The most important component of improved forest management programs is to reduce logging damage in selection/selective cuts.
- Planning component in planned harvesting = $72/ha.
- Logging efficiencies improved through sawyer finding trees quicker, skidder locating trees, skidding to landing - these efficiencies gain back about 13% of the planning cost.
- Also decreases costs by reducing the amount of waste and lost wood - by reducing the stumpage value per m^3 of harvested timber planned logging gains back another 91% of the planning cost.
- In the short term 25.4% of the harvested volume was wasted in the unplanned logging operation, through poor cutting techniques or lost logs.
- The authors feel that overall profit will be increased based solely on the short term costs.
- However, also need to look at the long-term yield from the forest.

Jonkers, W.B.J. 2002 Reduced impact logging in Sarawak, Guyana and Cameroon – the reasons behind differences in approach. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- In this paper, four cases are discussed in which the author was involved directly: the RIL methods developed in Sarawak in the 1970s, in Suriname in the 1980s and in Guyana and Cameroon in the 1990s.
- The Sarawak method was tested in a dipterocarp forest on undulating terrain, in a logging concession approximately halfway between the towns of Miri and Bintulu.
- About 14 trees/ha were harvested, yielding about 54 m3/ha.
- The Celos Harvesting System developed by Hendrison (1990) was meant for the “Forestry Belt”, a 40 to 120 km wide and 400 km long zone in the northern part of the country.
- The terrain is flat to undulating. ▪ Some 5-8 trees/ha are harvested, seldom yielding more than 20 m3/ha.
- The spatial distribution of commercial timber trees is usually random.
- Several RIL studies have been conducted in Guyana, but only the activity at the Tropenbos site near Mabura Hill is discussed here.
- Two RIL studies have been conducted in Cameroon, but only the Tropenbos study is discussed here.
- The Tropenbos site is located in the southwest of the country.
- In conventional logging, the area under skid trails was only 4.3 percent.
- With RIL just a modest reduction to 3.9 percent could be realized.
- More important is that after RIL skidding, part of the vegetation had survived on 47 percent of the trail length, compared to 29 percent after conventional logging.
- A difference in costs between RIL and conventional logging could not be demonstrated, although the RIL method is probably somewhat less expensive.
- In the case of the Sarawak Study: although the method had not been designed to reduce logging damage, the number of trees destroyed by logging had almost been halved.
- The Celos method (Suriname) significantly reduced logging damage.
- The area under skid trails was reduced by about 50 percent to a mere 5 percent of the total area.
- For Guyana, again, RIL reduced the area under skid trails by about 50 percent.
- The number of trees damaged by skidding was reduced by the same percentage.
- Felling damage was not reduced, however, and may even be more severe than in conventional operations if felling intensity is high.
- This is because in conventional logging, trees are more likely to be felled into existing felling gaps, thus creating less damage but larger canopy openings.
- In the case of the Sarawak Study: the planned way of working, logging costs per cubic meter extracted were reduced by 23 percent, which is due partially to lower skidding costs and partially because less timber had been wasted.
- For the Suriname study, the results were comparable to those obtained in Sarawak: additional expenditures for surveys, planning and pre-harvesting operations added about 5 percent to the logging costs.
- This increase was more than compensated for by reduced skidding costs and improved efficiency.
- For Guyana, the costs per cubic meter extracted under RIL were slightly less than under conventional logging.
- The difference would have been more substantial if the same felling limits had been applied in both methods.

Jonkers, W.B.J. & Schmidt, P. 1984 Ecology and timber production in tropical rainforest in Suriname. *Interciencia* 9(5): 290-297.

- Growth rates in plantations in Suriname have not met expectations.
- Plantation forests should only be put in places where the forest has already been destroyed.

- If tropical rainforest have to be used economically, other yield systems more adapted to the ecological conditions have to be developed and used (e.g., CELOS).
- Commercial species accounted for 117.1 stems/ha (BA=10.11 m^2/ha) (dbh >=10 cm).
- All species accounted for 476.9 stems/ha (BA=25.2 m^2/ha) (dbh >=10 cm).
- Describes the use of conventional unplanned logging and the associated problems.
- After logging the most likely impression of a visitor, walking on a skid trail shortly after logging, is one of almost complete destruction.
- In Suriname the logging intensity rarely exceeds 20 m^3/ha and the damage is considerable, but the forest is not destroyed.

Jonkers, W.B.J. & Hendrison, J. 1987 Prospects for sustained yield management of tropical rainforest in Suriname. *In*: *Proceedings of Management of the Forests of Tropical America: Prospects and Technologies*, San Jan, Puerto Rico, September 22-27, 1986. USDA, Forest Service, Southern Forest Experiment Station. p.157-173.

- Diameter growth in recently logged forest (trees dbh > 15 cm) was 0.43-0.52 cm/year, compared to 0.36 cm/year in unlogged stands.
- In Suriname logging intensity seldom exceeds 20 m^3/ha (1986).
- Logging damage with mapping of stems for felling only to avoid needless tractor driving within the stand (main experiment near Kabo, Suriname). Number of stems/ha and logging damage to commercial species only:

	Stems/ha	Percentage per damage category				
		Felled	Destroyed	Injury	No damage	Total
Level of exploitation: 15 m^3/ha						
5-15	87	0.0	12.2	2.6	85.2	100.0
15-35	51	0.0	7.4	9.9	82.7	100.0
35-65	35	4.4	4.3	12.8	78.5	100.0
>65	9	20.4	0.5	13.5	65.6	100.0
>15	182	1.9	8.7	7.1	82.2	100.0
Level of exploitation: 46 m^3/ha						
5-15	77	0.0	25.0	5.8	69.2	100.0
15-35	50	0.0	13.8	16.5	69.7	100.0
35-65	34	22.7	7.9	14.6	54.8	100.0
>65	8	48.5	4.2	14.2	33.1	100.0
>15	169	6.9	17.3	11.1	64.7	100.0

Jonkers, W.B.J. & van Leersum, G.J.R. 2000 Logging in south Cameroon: current methods and opportunities for improvement. *International Forestry Review* 2(1): 11-16.

- The study area is located on poor soils on the Central African Shield.
- The current basal area is 34m2/ha; the felling intensity varies from 0.3 to 1.8 trees/ha.
- 5.1% of the harvested area incurred disturbance caused by logging (felling 1.4%, skidding 1.1%, road and landing construction 2.7%).
- Approximately 30% of the damage due to roads and landings could have been avoided.
- About 20% of the skidding damage (e.g. dual trails, shortcuts) could have been avoided.
- The volume delivered to the sawmill was 70% of the amount felled. Losses occurred during felling (21%), topping (7-10%), logs not found (4%) and cutting off both ends of the log to give the timber a better appearance (4%).
- Liana cutting did not have a noticeable effect on logging damage.
- Directional felling did not reduce the damage to trees of commercial interest significantly.
- Skidding restrictions following rain also reduced damage, but lead to losses of output in all production phases. This may outweigh the benefits.
- About 20% of the harvesting damage could have been avoided using the full range of RIL elements (4 instead of 5% of the residual stand damaged).

Jonsson, T. & Lindgren, P. 1990 *Logging technology for tropical forests - for or against*? Forskningsstiftelsen Skogsarbeten, Report to the ITTO. 126pp.

- The report on the state of logging in the moist tropical forests based on a literature review and site visits.
- Logging is an integrated part of forest management; the way it is planned and executed affects both short- and long-term revenue from forestry.
- In the immediate future, it is more important to improve the use of available logging equipment than to develop new equipment.
- Frequency and intensity of logging are as important as the choice and use of equipment.

- Integrated forest enterprises involved in both logging and wood processing are most likely to take a long-term interest in forest management.
- Tropical moist forests (TMF) can be sustainably managed for timber and non-timber products; however, systems for sustained management of TMF are rarely implemented in practice.
- Many of the aspects of logging are not complicated; all that is needed is a little theoretical background and some down-to-earth practical work in the field along with common sense.
- RIL methods are well known but are not widely applied because of:
    - short term aims, and lack of planning and control
    - many forest operations focus on current cost minimization and profit maximization without consideration of the future
    - concession agreements, incentives and payment schemes do not stimulate sustained yield management and in fact often encourage the opposite
    - profit levels in tropical forestry have in many cases been extremely high, and thus the interested parties have been "spoiled" and are reluctant to accept any reduction in short term profit
    - knowledge acquired throughout research has not been broadly disseminated

- Survey results on what the forest authorities regard as most urgent to improve if sustainable forest management is to be achieved:

	Responses out of a total of 95
Better land use policies and plans	12
More serious enforcement of existing laws and regulations	11
Efficient control	11
Funds for forestry authorities	10
Better long range planning	9
Better planning prior to logging	9
Better training	9
Better recognition of the importance of the tropical forest	7
Better concession agreements	7
Proper and distinct laws	6
Better and more suitable machines	4

- Survey showed that the most widely used logging systems employed bulldozers or bulldozers in combination with skidders.
- A large number of forest industries can still afford to run inefficiently because of low log prices and easily available raw material. The equipment used is often of inferior quality and wastage is high. The export market has only accepted the highest qualities of timber and selected species and little has been done to change this.
- Industry is starting to realize the benefits of integration where there is tremendous scope for improvement.
- Formal vocational training in timber harvesting for forest workers exists only in a few places in the tropical world and only a couple of these training centres offer courses on a regular basis.
- To achieve more efficient and environmentally sound logging practices, training is urgently needed; if logging training is not given a higher priority; very little progress will be achieved in improving forest management and environmental protection.
- Ergonomics and work safety are central in forestry and harvesting but are grossly neglected.
- The great majority of loggers pay very little attention to the ecological consequences of their operations.
- 11 out of 13 responses from countries viewed current large scale logging practices as unsatisfactory in regard to sustainable management.
- The forest enterprise should either own the forest land or have its concession granted on a long-term basis; i.e., substantially longer than one cutting cycle and in such a way that retention of the concession is guaranteed as long as the conditions of the agreement are met.
- Felling is the most crucial phase of the operation because it influences efficiency, logging costs, the value of timber and silvicultural results.
- If the bulldozer is over-sized there is a temptation for the operator to use power instead of skill, while if the bulldozer is under-sized too much winching and equipment manoeuvring, and thus increased cost, can result.

- A compartment within a concession should be logged at one occasion only and then closed off to allow the forest to recover (30-40 years). Re-entry, after a short time, to harvest another species should be prohibited.
- Can reduce costs and impacts by using more species, but only up to a point that the stand can recover from efficiently.
- Should be better use of the resource at the stump and at the mill.
- Theoretical simulations of cost and yield showed a 20% reduction in cost through improved logging practices, while 5 m^3/ha or 7% more volume (based on a logging intensity of 60 m^3/ha) could be extracted through improved felling and bucking techniques.

Kammesheidt, L. 1998 Stand structure and spatial pattern of commercial species in logged and unlogged Venezuelan forest. *Forest Ecology and Management* 109: 163 – 174.
- The study was carried out in the Caparo Forest reserve which lies on the western plains of Venezuela. A polycyclic management system with a 30 year cutting cycle is prescribed in the study area. Silvicultural treatments prior or after logging have not been carried out. Three stands logged 5, 8 and 19 years prior to sampling were selected and compared with a mature forest stand. In each stand the area affected by logging was delimited.
- The impact of logging on the stand structure and spatial pattern of commercial species was studied along a chronosequence of 5-19 year old logged stands in the Forest Reserve of Caparo, Venezuela. For comparison, a mature forest stand was surveyed. A systematic sampling design was applied. On average 10.2 trees/ha with a bole volume of 66.5m3/ha were removed. Up to the mid-1980s, covered by this study, only *Bombacopsis quinata, Swietenia macrophylla, Cedrela odorata* and *Cordia apurensis* were logged. The 5, 8 and 19 year old logged stands show ed a mean basal area of 17.8, 21.3, and 22.2 m2/ha, respectively, whereas 33.2m2/ha were measured in the mature forest. The share of undamaged trees in the basal area increased from 30.8% in the 5 year old logged stand to 43.9% in the oldest logged stand. The number of emergent trees (>30 m height) was considerably reduced by logging; even 19 years after logging only 8 stems/ha were found in this height class comparing to 51 stems/ha in the mature forest. B. quinata, the most important timber species in the study area, occurred with only two heavily deformed individuals in the logged stands. Juveniles of B. quinata were rare (<10 stems/ha) in both logged and unlogged stands. A similar situation was found in C. odorata and S. macrophylla. In contrast, C. apurensis was well represented in small-sized shade-tolerant and light-demanding species which were regularly distributed in the unlogged and logged area. However, the spatial patterns of seedlings and saplings of these species did not show any clear trend. Nineteen years after logging, only one third (61.3m3/ha) of the commercial bole volume of the mature forest (185.3 m3/ha) was attained.

Karsenty, A. 1998 The economic implications of reduced impact and conventional logging. *In*: *Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantan*. Cirad-foret, France.
- The data for this study was collected from the STREK project in East Kalimantan (Indonesia).
- Efficiency and costs of intra-plot skidding:

Treatment	Volume extracted (m^3/h)	Costs ($/$m^3$)	Costs of trails ($/km/$m^3$)
RIL _50cm	48.42	2.95	7.38
RIL _60cm	46.53	3.14	11.25
Conventional	35.65	4.03	7.20

- It was estimated that the additional costs of the engineering needed for pre-planning and supervision of improved management should not exceed US$ 20 to US$ 25 per hectare.
- The cost-benefit analysis indicates that US$ 50 to US$ 74 can be saved per hectare with improved management.

Kartawinata, K. 1978 Biological changes after logging in lowland dipterocarp forest. *BIOTROP Special Publication* 3: 27-34.
- With a log extraction intensity of 25 trees/ha in an East Kalimantan forest it was found that the tractor paths amount to about 30% of the ground surface.

Kasenene, J.M. & Murphy, P.G. 1991 Post-logging tree mortality and major branch losses in Kibale Forest, Uganda. *Forest Ecology and Management* 46(3-4): 295-307.
- Annual rates of live tree falls per hectare were 1.30 lightly cut (14 m^3/ha), 3.30 heavily cut (21 m^3/ha and extraction tracks heavily disturbed), and 1.74 for uncut mature forest.
- Medium altitude tropical moist forest.
- In the utilization of tropical moist forest, emphasis should always be put on low disturbance levels similar to the natural rate of tree falls that form an integral component of the mature forest dynamics.

Kelvin, A. 1993 Estimate of timber production, capacity utilization and export potential in Zaire. *Commonwealth Forestry Review* 72(3): 175-180.

- The yield of exportable species in Zaire is limited for marketing and ecological reasons to 6-10 m^3/ha on a 25 year cutting cycle; e.g., in the Atlantic province of Bas Zaire, where the forests have been creamed.
- Experts interviewed believe that new concessions in other provinces deeper in the hinterland can yield 20-22 m^3/ha.
- If all species currently used by foreign and home markets are taken into consideration the yield (according to those interviewed) could reach 50 m^3/ha.
- With promotion of additional species the yield could be further increased to 60-70 m^3/ha.
- There is no scarcity of forest reserves; the question is how to put forest resources to good use.

Kho, P.C.S. & Chan, B.S.T. 2002 Directional tree felling training programme: an association's approach. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- In June 1996, the Sarawak Timber Association (STA) collaborated with the SFD, to start a tree-felling training program to supplement existing training programs provided by the SFD and other government agencies.
- STA has been involved in the training of tree fellers for about 36 months and has so far trained 508 persons.
- The training concentrated mainly on occupational health and safety and directional felling.
- STA faced the following problems: (a) lack of availability of qualified trainers and an appropriate curriculum (b) difficulties in access to the training sites (c) cultural (esp. language) barriers and (d) the high cost of training.

Kilkki, R. 1992 *Reduction of wood waste by small-scale log production and conversion in tropical high forest. Forest Harvesting Case Study No. 1*. Food and Agriculture Organization of the United Nations, Rome, Italy, 33pp.

- Studies by FAO have shown that nearly half of the timber volume felled during commercial harvesting operations in tropical forests remains in the forest as unutilized residues after the loggers have departed.
- Papua New Guinea:
    - after commercial logging 60 m^3/ha of merchantable size standing timber left, plus 30 m^3/ha of uncommercial mature trees
    - volume of trees damaged during traditional logging operations and left in the forest was found to be about 15 m^3/ha in size classes from 20-50 cm dbh (i.e., 17% of total volume)
    - the number of stems damaged (dbh >20 cm) was 229 of the 673 residual trees or 34%
    - 10.35% of the export volume was left at the harbour as not fulfilling export grading rules
    - uses a vertical circular saw 32 inches in diameter and a horizontal 12 inch diameter saw
    - annual round wood production of 5 million m^3 from 80 000 ha (62.5 m^3/ha calculated logging intensity).
    - 50 cm minimum dbh (60 cm minimum dbh for companies exporting logs)
    - skill of the sawmilling crew is imperative in recovery and quality of product
    - logging intensity is 5-8 stems/ha or 30 m^3/ha on average
    - average portable sawmill recovery was 52% (44-56% range)

Killman, W., Bull, G. Q., Schwab, O. & Pulkki, R.E. 2002 Reduced impact logging: does it cost or does it pay? *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- Two hundred and sixty-six studies and articles on RIL and/or CL, conducted in closed broad-leaved tropical forests, were reviewed and classified.
- These publications dated back to 1950. Following compilation and analysis, the data extracted were summarized in order to give an indication of some general trends.
- It should be noted, however, that the data found in the various reports are not adjusted to account for inflation.
- From a summary 130 observations (n=37 for RIL and n=93 for CL).
- The median[2] volume harvested was 8 m3/ha lower, with RIL at 37 m3/ha and CL at 45 m3/ha.
- In the majority of the RIL studies the logging intensity was <60 m3/ha, while for CL there was a significant portion >60 m3/ha.
- 101 observations (45 RIL and 56 CL) showed no significant difference in the number of trees harvested per hectare between the two forms of logging.
- The median number of trees harvested was 8 trees/ha for each cutting cycle.

- 21 observations indicated that utilization rates are better with RIL; however, many more studies are needed.
- From 75 observations RIL had 41 percent less residual stand damage, when compared to 49 percent for CL systems.
- Other studies which measured stand damage in a different manner, found that median rates of damage for RIL and CL were 124 and 131 trees per hectare, respectively.
- In 15 observations the damage to trees per trees felled was 56 percent less in RIL operations when compared to CL operations.
- The area covered by skid trails in RIL operations is almost 50 percent less than in CL.
- From eight observations of road damage, the trend was as expected with a much lower level of damage (41 percent) when using RIL techniques.
- In 25 observations with RIL the canopy opening was 36 percent smaller.
- In 33 observations the adoption of RIL resulted in the volume of lost timber being 60 percent lower than in CL operations.
- In 10 observations the median cost of RIL was US$ 0.28/m^3 higher than that of CL. In another two observations the planning costs were reported as costs per hectare.
- The range of US$ 5.06 to US$ 50.00/m^3 indicates serious shortcomings in the statistics on planning at this time.
- In a total of 10 observations, the median felling cost of RIL was US$ 0.56/m3 higher than that of CL.
- This represents a cost that is 48 percent higher. In a review of 11 articles no appreciable difference in skidding costs between the two forms of logging was found.

Kittredge Jr., D.B., Finley, A.O. & Foster, D.R. 2003 Timber harvesting as ongoing disturbance in a landscape of diverse ownership. *Forest Ecology and Management* 180 : 425 – 442.
- To examine the value of state-wide regulatory data for Massachusetts as a unique source of this critical information, 17 years of timber harvest data gathered for regulatory purposes for a 168,000 ha forested landscape in Massachusetts was analyzed.
- The predominant form of harvesting was selective removal of commercially valuable tree sizes, grades and species.
- The spatial pattern of logging was random with regards to major physical, biological, or cultural factors.
- However, logging was strongly related to landowner class.
- NIPF owners control 60% of the forest area and were responsible for 64.1% of harvest area, but the highest logging intensity (volume per area harvested; 69.3 m3 ha-1) among major landowners was conducted by the state agency responsible for managing southern New England’s largest conservation property, the watershed of Boston’s drinking reservoir.
- Annual disturbance rate of 1.5% and a mean intensity of 44.7 m3 ha-1 (approximately one-fourth of average stand volume).

Klassen, A.W. 2002 Impediments to adoption of RIL in the Indonesia corporate sector. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- Most forest concessionaires follow the Indonesian Selective Cutting and Planting System (TPTI) and carry out 100% inventories and most of the regulatory requirements. However, combined with an almost total absence of effective field monitoring and enforcement of existing regulations, TPTI is ineffective.
- RIL research results in Southeast Asia indicate clear benefits from a productivity point of view and well as environmental benefits. However the financial benefits are not clear and in light if the uncertainties facing the industry in Indonesia, financial benefits must be clearly articulated.
- The focus should now be on the implementation of RIL in Indonesia.
- Forest companies and forest managers must educate themselves on RIL. Forest operations must be examined and adjustments made where necessary. Gaps in the knowledge and skill levels need to be identified and filled by thorough training.
- Governments and funding agencies need to place greater emphasis on the development and delivery of training and extension programs for the forest industry.

Klassen, B. & Cedergren. J. 1996 Felling the right way. *ITTO, Tropical Forest Update* 6(3): 5-7.
- Directional felling is done to minimize damage to the log, minimize damage to the residual stand, and to facilitate log extraction.
- Direction felling is more time consuming than haphazard felling, but gains in these three areas will almost certainly outweigh the costs.

Kleine, M. & Heuveldop, J. 1993 A management planning concept for sustained yield of tropical forests in Sabah, Malaysia. *Forest Ecology and Management* 61(3-4): 277-297.

- In many regions of the tropics, forest managers are today confronted with the situation that the natural primary forests have either already disappeared or will do so in the very near future.
- Left over are residual forests which are considerably different to the primary forests in respect of species composition, structure, dynamics and ecological stability.
- Of fundamental importance to change from pure exploitation of the forest to sustainable forest management practice.
- Failures in tropical forest management are mainly due to the lack of proper enterprise management, as well as to unfavourable macro-economic framework conditions.
- One of the issues most intensively discussed among forest managers ins the estimation of the volume of timber which can be harvested on a sustainable basis.
- An example of a production goal applicable to the present condition of a logged-over lowland dipterocarp forest is Sabah is: local tropical hardwood/high value product; 15-30 trees/ha >60 cm dbh of light and medium hardwood dipterocarp and non-dipterocarp; more than 50% veneer quality; uneven-aged structure.
- Based on silvicultural experience in Sabah, a dipterocarp stand can produce 15-30 trees/ha (>60 cm dbh) of marketable timber species at the end of a cutting cycle, average tree size of 3 m^3, gives 45-90 m^3/ha.
- The cost for medium-term management planning is 14 USD/ha or 0.70 USD/ha/year on a 20 year management planning period.

Korsgaard, S. 1985 *Guidelines for sustained yield management of mixed dipterocarp forests of South East Asia.* Food and Agriculture Organization of the United Nations, GCP/RAS/106/JPN, Field Document 8. 78pp.

- Based mainly on work in Kuching, Sarawak, Malaysia.
- At present the sustainable level of production is estimated at 2 to 3 m^3/ha/year of net industrial volume of desirable species over 30 cm dbh.
- After a period of 40 years the accumulated production should be about 80 m^3/ha of which 50% can be utilized. The average net industrial volume possible to take out after 40 years will be about 40 m^3/ha, which is at a level equivalent to that of the initial harvest.
- This paper outlines RIL.
- Mono-cyclic systems have a rotation length of 70 to 80 years, are expensive and ecologically less desirable.
- Poly-cyclic systems have a cutting cycle of 35-40 years, concentrate efforts where the highest returns can be expected and the system is ecologically acceptable.
- In many cases half or more of the trees remaining after logging are damaged, some of them so badly that they will die.
- The area lost to roads, landings and trails varies considerably depending on the terrain, the harvesting system and the individual operator. Currently, as a rough estimate, at least 10% of the area is lost and must be deducted from the productive forest area.
- Few secondary forest areas have been left undisturbed sufficiently long to yield conclusive evidence of the attainable level of production; indications are that the production is around 1.5 3.0 m^3/ha/year.
- In one example of RIL in Sarawak the residual stand consisted of 380 trees/ha (21 m^2/ha of basal area), which was sufficient to produce a second crop in 35 to 40 years time.
- The problem in many cases is that when the market picks up many of the trees left after the first logging become profitable to extract. Re-entering the forest causes heavy damage to the young seedlings and saplings. By repeated re-entering the forest is gradually damaged beyond the level where it is able to regenerate natural. The relogged forest often deteriorates into a state of unproductive weeds.
- Unfortunately many of the dipterocarp forests in Southeast Asia have been badly damaged by logging disregarding the fact that wasteful and damaging harvesting is more expensive and at the same time gives a lower rate of production than does a well planned and carefully supervised harvesting operation. Careful harvesting extracts more of the felled trees and leaves a less disturbed forest with greater potential to rehabilitate itself.
- The conclusion is: there is no reason to tolerate harvesting operations that are wasteful and damaging.

Kramer, R., Healy R. & Mendelsohn, R. 1992 Forest valuation. *In*: Sharma, N.P. (ed.). *Managing the World's Forests*. Kendall/Hunt Publishing Co., Dubuque, Iowa. p.237-269.

- Under-valuation of forests has caused governments to assign a low priority to the forestry sector because of its apparently low contribution to gross national product (GNP).

Kuusipalo, J., Kangas, J. and Vesa, L. 1997 Sustainable forest management in tropical rain forests: A planning approach and case study from Indonesian Borneo. *Journal of Sustainable Forestry* 5(3/4): 93-118.
- The study area is located in South Kalimantan.
- The average volume of marketable tree species with a diameter >50cm is 120m^3/ha.
- A harvesting intensity of 40m^3/ha is possible if a 35-year cutting cycle is applied.

Lamprecht, H. 1993 Silviculture in the tropical natural forests. *In*: Pancel, L. (ed.), *Tropical Forestry Handbook*. Springer-Verlag, Heidelberg, Germany. p.728-810.
- In the tropics proper forestry and silviculture are the exception.
- Only 1-5% of the topical forests are under sustained-yield management.
- The preservation of the tropical rain forests seems only possible by replacing the traditional wasteful methods of need satisfaction with usage that is based on sustained yields.
- The necessary basic knowledge, as well as suitable silvicultural technologies, are available.
- These are outlined in the chapter.

Laurance, W.F. & Laurance, S.G.W. 1996 Response of five arboreal marsupials to recent selective logging in tropical Australia. *Biotropica* 28(3): 310-322.
- Selective logging of topical rain forest in Queensland, Australia.
- 150 ha site in which an average 8-10 trees/ha were removed (50-55 m^3/ha) in 1987-1990.
- Site had been lightly logged in the 1920's with bullock teams.
- 14 species comprised 95% of the volume, and 4 species comprised 50% of the volume.
- In previously logged areas (1979-1980) the logging intensity was 34.4 m^3/ha.

Lee, H.S. 1982 The development of silvicultural systems in the hill forests of Malaysia. *Malaysian Forester* 45(1): 1-9.
- In the hill forests of Sarawak the number of trees/ha removed varies from 4 to 20.
- The average logging intensity (1974-1978) was 25 m^3/ha, with the standing volume being 94-145 m^3/ha.
- Planned logging cycle is 25 years, but the author doubts this short of a cycle is appropriate, especially due to the high damage factor that must be accounted for.
- Lack of planned skidways in the forest leads to the creation of numerous tractor paths for seeking logs.

Leslie, A. 1977 Where contradictory theory and practice co-exist. *Unasylva* 29(115): 2-17.
- As a general rule logging costs generally account for 25-35% of the price of processed wood.
- It is fairly common experience to fine logging costs in tropical forests varying by as much as 50% between operators.
- Quite often, inefficiencies in logging are the result of anachronistic and badly administered procedures and regulations, or of lax supervision and control measures.

Leslie, A.J. 1987 A second look at the economics of natural management system in tropical mixed forests. *Unasylva* 39(155): 293-295.
- prominent feature of tropical forest management is the limited success of natural management systems - more often than not, this lack of success is the result of no management at all, rather than the failure of natural management
- the tropical moist forest can survive only if the land itself is seen by the people concerned to be more valuable retained as forest than converted to any other form of land use
- natural management of the tropical mixed forest, wherever it is ecologically feasible, is also, on its own merits economically preferable

Lindgren, P. 1992 Just beyond the obvious. *In*: *Beyond the guidelines - an action program for sustainable management of tropical forests.* International Tropical Timber Organization, Technical Series No. 7. P.37-45.
- The vision - we want machines that do not waste or destroy, either nature or the operator.
- The vision - felling a tree without damage to the remaining stand, or to the tree itself or the operator. Or machines with high traction, high ergonomic standards, low ground pressure, good manoeuvrability, a high payload and which are easy to service and operate, and low price.
- The vision - on the human side there is planning, organization, leadership, education, teamwork, well-being, nourishment, incentives, etc.
- The following are possible and occur in the topics - tropical forests can be used for many purposes (only one is timber production)/sustainable management is possible/logging damage can be reduced and efficiency improved/harvesting equipment and knowledge of how this equipment should be used is already to a large extent at hand.

- Why not implemented, because - actual targets are cost minimization and profit maximization/incentives and payment schemes are constructed so as to effectively sustain these targets/short-term thinking/concessionaires and loggers and sometimes industry are separate entities/profit levels have often been so high that any adjustment towards less is regarded as highly disadvantageous.
- Technical adaptations must be coupled with changes to the institutional framework and intensified training and education. It is the way the equipment is used that causes the greatest damage - it is the malpractice more than inadequate equipment that causes the greatest adverse effects. At the same time there are simple technical things that are neither known, nor used.
- Loggers are often ignorant and are not aware of how the economy of their operations benefits from using more efficient and better adapted machines and work methods.

Loehnertz, S.P., Cooz, I.V. & Guerrero, J. 1996 Hardwood sawing technology in five tropical countries. *Forest Products Journal* 46(2): 51-56.
- Countries studied were Ghana, Brazil, Venezuela, Indonesia and Malaysia; account for about 21% of the world's total hardwood sawn wood.
- Knowing how to efficiently process its wood enhances present and future value of the forest.
- Sawmill recovery for U.S. hardwood mills is likely in the range of 45 to 55%.
- Sawmills in tropical countries will more likely process larger diameter logs (yield should be higher).
- In Africa more than 90% of the sawing machines are bandsaws.
- In Ghana, lumber is not planed and average yield is 40%, increasing to 50% in the best case.
- Many reported problems in Ghana are related to maintenance (e.g., saw being used when dull, gullet burn while sharpening, incorrect and uneven tension, uneven crown, burrs left in gullet when sharpened, faulty wheel bearings, saw too thick for wheel dimensions and bandmill vibration). Lack of skilled labour and management is partly to blame.
- In Brazil there is highly selective forest exploitation, scarcity of qualified personnel, and obsolete equipment and inadequate maintenance structure.
- Maranhao State (Brazil) the lumber recovery from three Cikel Sawmills (bandsaw mills) was about 55%, with only part of the mill production being planed.
- In Para the wood is harder and of higher moisture content than in other parts of Brazil, and recovery can be very low at 20% (80% fibre loss with 60% lost in the forest and another 20% in the mill).
- In Venezuela almost all sawmills use bandsaws and the usual recovery from a saw log is 60 to 70% in sawn wood of commercial dimensions; the value seems unusually high, but the basis of computation is unclear.
- In Indonesia, the waste from logging may exceed the log volume extracted, perhaps by 1.5 to 2 times, when considering damage to the stand and the full range of log diameters (Mordeno 1990).
- In Indonesia, problems that have contributed to the low performance of the industry (yield less than 50%) include inefficient production techniques and machinery, lack of skilled labour and poor managerial skills.
- In Malaysia bandsaws are almost exclusively used, and throughout the industry the average recovery rate is 54.5%.
- In general, the density of wood and occurrence of silica make it a challenge to saw many tropical hardwoods, and the most commonly reported sawmill problems include poor maintenance, lack of trained personnel, obsolete equipment, and inadequate sawtooth geometry and wear resistance.

Long, A.J. 2001 *Environmentally Sound Forest Harvesting*. School of Forest Resources and Conservation, Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida.
- Harvesting trees is a tool for accomplishing many management objectives, and operations can be conducted to protect environmental quality and reduce visual impacts.
- Key requirements for environmentally sound harvesting will include good planning, reputable contractors, skilled workers, and professional foresters who understand the concepts and application of sound forest practices.

Lowe, R.G. 1978 Experience with the shelterwood system of regeneration in natural forest in Nigeria. *Forest Ecology and Management* 1(3): 193-212.
- Paper outlining the Nigerian Tropical Shelterwood System and its history.
- This was the dominant method used until the 1960's when there was a change in emphasis to artificial regeneration.
- However, still most of the volume was from natural forests.
- Natural forests are not adapted to withstand heavy exploitation or to maintain high increments.
- For this reason the author saw the need to change to intensive plantation forestry to supply the fibre needs.

- Also it was noticed that the success of the system probably depended more on advance growth than on regeneration stimulated by the shelterwood operations themselves.
- The increment for the natural forest is about 2 m^3/ha/year.
- On average less than 20 trees/ha with dbh >50 cm.
- On average 5 trees/ha (dbh >80 cm for some species) were utilized.
- Logging intensity in the 1940-50's was less than 20 m^3/ha, compared to a total stem volume >200 m^3/ha.
- Logging intensity has increased.
- With current methods, the total exploitable volume averages about 100 m^3/ha of which 30 m^3/ha is actually extracted, on a cutting cycle of 50 years (was reduced from 100 years).
- Total volume in stems >40 cm dbh was 100 m^3/ha, and for trees >60 cm 75 m^3/ha.
- A growth rate of 15 m^3/ha/year with a total exploitable volume of 300 m^3/ha is given for plantations.

Lowe, R. 1992 Volume increment of natural tropical moist forest in Nigeria: a preliminary account of the high forest monitoring project. *In*: *Beyond the guidelines - an action program for sustainable management of tropical forests*. *International Tropical Timber Organization, Technical Series* No. 7. P.150-151.
- Study of five high forest reserves in different climatic/geographic regions of Nigeria.
- Mean annual increments for bole volume were about 5.0 m^3/ha/year plus or minus 1.0 m^3. This included 2.5 m^3 for exploitable species and 1.2 m^3 for veneer quality species. Standing bole volumes ranged from 110 to 340 m^3/ha, and standing basal areas from 16 to 37 m^2/ha. Exploitable species accounted for about half the total standing volume of the forest.
- The results suggest that the forests can withstand removals from an annual coupe equivalent to 50 m^3/ha of the standing bole volume on a 25 year felling cycle (35 m^3/ha in terms of log removals) without serious damage to the forest - although the relative proportions of species may change as a result of repeated exploitation.
- Necessary to set minimum felling diameters for the various species.
- For example, in species valued for decorative wood, such as the mahoganies, the heartwood is coloured whereas the sapwood is white and is less durable than the heartwood; moreover, larger trees put on proportionately more wood for the same diameter increment besides being the main seed bearers.
- Some species requiring a minimum felling diameter of as much as 80 cm or 90 cm, while other species do not grow to large sizes, and require lower minimum felling diameters of perhaps 40 cm DBH.
- The length of felling cycles is limited by a minimum period which allows the weed growth following exploitation to be shade out (perhaps 15 years), but not so long that exploitable trees are lost due to over maturity.
- However, the present situation in Nigeria is that none of the high forest reserves are currently being managed under working plans, and exploitation is scarcely regulated - and is proceeding to an extent that is destroying the recuperative capacity of the foret. This extends to secondary forest products that are garnered in the forest, such as chew sticks, wrapping leaves, spices, medicinal materials and bush meat. These are important for the livelihood of local communities and need to be brought within the ambit of the forestry working plan.

Macedo, D.S. & Anderson, A.B. 1993 Early ecological changes associated with logging in an Amazon floodplain. *Biotropica* 25(2): 151-163.
- A study of selective logging of high density virola (*Virola surinamensis* (Rol.) Warb.) stands in the basin of the Rio Preto (Amazon).
- Charcoal deposits in the area suggest that the currently high density of virola could be indicative of old successional forest (major fires in region in early 1900's).
- First logging started with removal of larger trees >45 cm dbh for plywood production, followed by sawmillers removing material under 30 cm dbh.
- Floodplain logging in the area is manual; axes are used for felling and cross-cutting.
- Wood is floated out along hand-dug canals during the wet season.
- In other floodplain areas inventories have shown an average density of 10 virola trees/ha with dbh >= 15 cm, however, in the study area it was 265 virola trees/ha with dbh >= 15 cm.
- Most logging impacts appear to be concentrated along a narrow strip (average 73 m) of forest adjacent to the canals, however, secondary canals extend the impact each year.
- First the larger wood was removed, followed by successive removal of smaller material.
- After 5-years of logging the understory consisted of a dense secondary community dominated by vines and herbs.
- Inventory of the area found that the bole volume of virola (dbh >= 5 cm) was 243 m^3/ha (62% of the bole volume for the entire swamp forest).
- Virola trees with diameters as low as 26 cm are harvested.

- It was estimated that 145 m^3/ha of virola are extracted under current logging operations. To harvest that wood, loggers must fell a total volume of 218 m^3/ha or 90% of the virola stand and at least 56% of the entire swamp forest. Due to inevitable damage to the residual stand the 56% of the entire forest is an underestimate.
- Brazils environmental regulatory agency, IBAMA, stipulates a minimum diameter limit of 29 cm for marketed virola logs and minimum felling diameter of 45 cm dbh.
- Log checks found that 22.1% of the logs were below the legal limit and it was estimated (based on form factors and regressions) that 70% of the felled trees would be below the minimum tree size.
- Reference to Rio Mocoòes (Uhl 1990) where logging intensity was 5 m^3/ha and 10% of the remaining trees were damaged in the removal of virola in a swamp forest and thus low impact with good regeneration and sustainability (unless the sawmillers move in and start removing the smaller pole-size material).
- In the case of this study the logging was unsustainable due to high logging intensity; after the first year of logging virola's basal area plummeted from 24.6 m^2/ha to 2.3 m^2/ha, and over a five year period seedling density per m^2 declined from 2.3 (year 0) to zero (year 5).
- Like previous economic booms in the Rio Preto, logging of virola is thus destined to be a short-lived activity.
- Given virola's economic importance and high potential under sustained yield management, its demise under current logging practices is especially tragic.
- The log-size and minimum tree dbh limits are impossible to enforce; e.g., the IBAMA station in the town of Breves maintains only one forest guard responsible for the entire estuarine area. Enforcement of forestry policies pertaining to virola, as well as to other forest resources in the Amazonia, is woefully inadequate.
- In addition to wood supply problems for the local industry, the demise of virola will lead to increased pressures on a wider range of alternative forest resources, thus exacerbating the ecological impacts of current logging practices in the region.

Machfudh, Sist, P., Kartawinata, K. & Efransjah 2001 Changing attitude in the forest. *ITTO, Tropical Forest Update* 11(2) : 10 – 11.

- PT Inhutani II, a state owned logging company, collaborated with CIFOR in an ITTO funded project to test the RIL approach in its operations.
- The main components of the include the development of appropriate logging guidelines and staff training.
- The area of skid trail per volume of timber extracted was twice as high in the conventionally logged blocks than in the RIL blocks (18.6 m2/m3 vs. 8.6 m2.m3).
- Damage to the stand and canopy increased with felling in the RIL blocks but not in the conventionally logged blocks.
- Under high felling intensity (> 9 trees/ha), the proportions of damaged and dead trees in RIL were similar to those recorded in conventionally logged sites.

Malinovski, J.R. 1996 Problems and chances for forest operations in Amazon Basin. *In*: *Proceedings of Forest Operations for Sustainable Forestry, XX IUFRO, World Congress*, August 6-12, 1995. IUFRO S3.05-00 and CIFOR Publication. p.47-49.

- A 100% inventory of trees >50 cm dbh in an Amazon forest, clay soils and slopes 0-25% yielded 18.7 m^3/ha of commercial volume:
    - 12.5 m^3/ha of plywood logs
    - 1.0 m^3/ha of veneer logs
    - 5.2 m^3/ha of sawn wood
    - 4.1 m^3/ha of non-commercial species
- Paper outlines RIL techniques.

Malmer, A. & Grip, H. 1990 Soil disturbance and loss of infiltrability caused by mechanized and manual extraction of tropical rainforest in Sabah, Malaysia*. Forest Ecology and Management* 38(1-2): 1-12.

- New tractor tracks (D4 and D6 class crawler tractors) cover 25% of the area in the mechanically extracted area.
- For the manual extraction area (kuda-kuda) the area of skid trails was 4% of the area.
  · During rain the extraction stopped, and for heavy storms normally stopped for one or two days due to the tracks being too slippery.
- Along the most heavily used parts of the tracks, up to 1 m of the upper soil layers were pushed aside.
- In some wet places, soil was bulldozed into them or new tracks were established around them.
- In the top 10 cm, mean dry bulk density increased after all treatments, but was significant only in the top 5 cm on clay soil after tractor extraction (increased from 0.82 to 1.28 g/cm^3).

Malvas, J.D. 1987a *Development of forest sector planning, Malaysia: logging. Food and Agriculture Organization of the United Nations, FO:DP/MAL/85/004, Field Document* 6. 90pp.

- Contract fellers have scant regard to felling sequence considerations or to damages to forest growth. · To exceed their production figures, tractor operators bulldoze their way often carelessly to felling concentrations and thereby damage regeneration and the soil.
- Studies in dipterocarp forests on logging wastes show that for every 100 m^3 extracted, 80-105 m^3 of logging wastes are left behind considering materials with minimum dimensions of 0.91 m long and 30 cm diameter (9.3% stumps, 31.4% tops and branches, 2.3% end trims, 50% damaged residual trees and abandoned logs).
- Weidelt and Banaag (1982) (note: could not find report) studied logging damages in Mindanao , Philippines and found the following tractor skidding damages:

Method of logging, damages and terrain conditions	**Residual dipterocarp, %**	**Residual non-dipterocarp, %**
A. Tractor skidding		
- felling damages	13.1	53.3
- skidding damages	22.1	
Total	35.2	
B. Highlead, rolling terrain		
- felling damages	16.7	58.0
- yarding damages	38.7	
Total	55.4	
C. Highlead, rough terrain		
- felling damages	14.1	62.3
- yarding damages	52.0	
Total	66.1	

Malvas, J.D. 1987b *Development of forest sector planning, Malaysia: a report on the logging demonstration cum training coupe. Food and Agriculture Organization of the United Nations, FO:DP/MAL/85/004, Field Document* No. 7. 43pp.

- Study of RIL with tractor skidding and highlead yarding to demonstrate the potential benefits through reduced destruction to residual and environment, and cost effectiveness.
- RIL must ensure that an adequate number of 20-60 cm dbh trees/ha are retained in a healthy state after logging through the implementation of selection logging techniques.
- In ground skidding area 89 m^3/ha available for harvest.
- Optimum feeder road density was 12.5 m/ha (i.e., road spacing 800 m = average skid distance 400 m (straight-line)).
- 70.42 m/ha of skid trails laid out (width D7 blade width of 4.17 m + 0.5 m = 4.67 m) and covered 3.3% of the area.
- Optimal (i.e., minimum) total area covered by roads, landings and skid trails slightly over 5%.
- Comparison of the number of advanced regeneration left per hectare after logging with supervised (48 ha) and unsupervised (21 ha) felling (tractor skidding):

	Supervised felling		**Trees/ha remaining**
Dbh classes	**Trees/ha marked for retention**	**Trees/ha remaining after logging**	**after unsupervised felling**
20-29	9.16	6.42	5.88
30-39	6.83	5.48	2.79
40-49	2.29	2.86	2.46
50-59	3.26	2.64	1.12
60-69	1.56	1.58	-
Total	23.10	18.98	12.25

- An accurate topographic map with 5-10 m contour interval will speed up planning and layout of skid trails.
- The use of felling tools is a prerequisite for successful implementation of directional felling.
- Tree marking as a selective logging activity is futile without directional felling.
- Directional felling saves more crop trees than the uncontrolled operation (19/ha vs. 12/ha).
- Bucking length instructions imposed in the woods definitely increases log utilization efficiency of wood processing mills, however, odd length logs could be left in the woods.
- Utilization of the tractor skidder was only 62% of an eight hour day.

Margules, S.R., Nelson, D., Petr, T., Ravuvu, A., Sundberg U. & Watling R. 1987 *Study of the environmental impacts of logging: Navua-Navutulevu Concession Area - Vitilevu. Food and Agriculture Organization of the United Nations, TCP/FIJ/6652, Field Document* 1. 108pp.

- Mini-EA study of logging in a concession in Fiji.
- Logging intensity is 40-50 m^3/ha (min. dbh 35 cm), from a total wood biomass estimated at 250 m^3/ha (minimum dbh not stated but assumed to be 10 cm).
- 30-40 years given as the period for logging all natural forest on the concession.
- Assessed disturbance 62% of area (light disturbance 45%; heavy disturbance, skid tracks and skid roads 12%; and landings and roads 5%).

Marsh, C.W., Tay, J., Pinard, M.A., Putz, F.E. & Sullivan, T.E. 1996 Reduced impact logging: a pilot project in Sabah, Malaysia. *In*: A. Schulte and D. Schöne (eds.). *Dipterocarp Forest Ecosystems: Towards Sustainable Management*. World Scientific Publishing Co. Pte. Ltd., Singapore. p.293-307.

- An essential requirement for sustainable forest management of tropical forests is a selective harvesting system that minimizes incidental damage to the residual stand and soil.
- Important in RIL are pre-harvest planning including preparation of a large scale stock/terrain map (1:5000), advance vine cutting, directional felling towards pre-planned skid trails, and above all, close supervision of tractor operations, so as to minimize skid trail length and blade use (also need to use the winch).
- After logging the area must be closed from further operations and skid trails rehabilitated.
- Post harvesting monitoring of success/failure of logging operations is a component of RIL.
- Research plots demonstrated more than 50% reduction in all measures of damage compared with conventional logging for an increase of about 10-15% in direct logging costs.
- Restrictions on wet-weather skidding slowed harvesting operations considerably in RIL areas and added to the cost.
- Additional considerations are the needs for training, operational stoppages after heavy rain, and the opportunity costs of retaining trees on very steep slopes and along riparian reserves.
- RIL not only minimizes all external environmental costs but also assures greatly improved future harvests with little or no need for further silvicultural treatment.
- In regard to timber certification, RIL opens the possibility of additional market-related benefits.
· Study area was 1400 ha.
- By Federal Government mandate from 1984, all forest reserves in Sabah are supposed to be managed on a sustainable basis. In practice, little evidence exists to suggest that this is the case.
- In eastern Sabah the average log weighs 7-9 tons and 80-100 m^3/ha are extracted.
- In the RIL logged area skid trail area averaged 3.4% of the area, compared to 12% in adjacent conventional logging areas, of which 38% of the skid trails in the RIL area has subsoil exposed, while in the conventional area 87% of the skid trails had subsoil exposed.
- Timber volumes extracted and logging damage in Sabah, Malaysia. Mean values (with standard deviations) from four logging units of each logging method:

	Conventional logging area	**Reduced impact logging area**
No. of trees extracted per ha	13.6 (2.7)	8.8 (3.6)
Timber volume extracted, m^3/ha	139 (23)	103 (54)
Percent of area with soil disturbance	17 (2)	7 (3)
Skid trail density, m/ha	199 (36)	67 (26)
Percent of trees killed during logging (5-60 cm dbh)	41 (11)	15 (7)
Density of undamaged saplings (5-20 cm dbh) per ha	49 (24)	104 (62)

- Four types of costs associated with RIL:
    - direct costs from more careful planning, climber cutting, tree marking, directional felling, better road construction standard, etc.; as RIL becomes more common these costs may add 10% to the direct operating costs
    - cost associated with the need for prior training and research required for the introduction of RIL
    - indirect cost due to weather delays when men and equipment are idle for 24 h after a heavy downpour
    - indirect opportunity cost of not extracting timber on steep slopes, although these areas could be reserved for logging with skyline or helicopter logging systems

- There are also cost savings in RIL; bulldozer maintenance and operating costs reduced, skidding production increased.
- There is the longer-term cost saving in silvicultural inputs and increased/maintained timber yields in the future.

Martini, A., Rosa N. & Uhl, C. 1994 A first attempt to predict Amazonian tree species threatened by logging activities. *Environmental Conservation* 21(2): 152-162.
- Summarizes information on ecological characteristics of 305 timber species in Brazilian Amazon.
- Developed a scoring system to rank species with regard to their hypothesized ability to withstand logging impacts.

Mason, D. 1996**.** Responses of Venezuelan understory birds to selective logging, enrichment strips and vine cutting. *Biotropica* 28(3): 296-309.
- Humid evergreen tropical forest with a canopy that varies from 30-35 m with emergents reaching 50 m in height.
- Although 37 commercial species in the area, 75% of the volume extracted was "mureillo" (*Erisma uninatum, Vochysiaceae*).
- Minimum felling dbh is 40 cm.
- Felling with chain saws and extraction with skidders.
- For 1988-93 2.9-7.3 trees/ha (5.8-14.2 m^3/ha) were authorized for extraction, however, the actual extraction rate was lower and reached 2.3 trees/ha (7.1 m^3/ha).
- Tree basal area in unlogged forest was 32 m^2/ha, logged 23 m^2/ha and logged with linear strip planting 20 m^2/ha.

Masson, J.L. 1983 *Management of tropical mixed forests: preliminary assessment of present status. Food and Agriculture Organization of the United Nations, Mimeograph* FO:MISC/83/17. 54 pp
- Maintenance of the ecological balance of the forest ecosystems in many instances has been more or less disregarded, mainly due to inadequate knowledge of the systems and of the silvicultural requirements of many of the species that compose the tropical mixed forest.
- Tropical forest management started in India and Burma more than a hundred years ago.
- Today only 4.4% of the tropical closed production forest is reported to be under management (which does not mean that intensive high yielding systems are used).
- Taking into consideration the relatively long time it takes most timber species to reach maturity there really has been little time to develop viable management systems for the complex tropical mixed forest.
- Stands containing more than 150 different species of trees on a single hectare are common in some tropical forest types and even in comparatively simple forest types in the tropics it is not unusual to have 30 species occurring in intimate mixture on a single hectare ... compare this to Sweden which has some 40 tree species, while tropical Madagascar has more than 2000 (both countries have similar forest areas of about 20 million ha).
- In all tropical broadleaved forests only about 6.5% of the standing gross volume is actually commercialized.
- In the majority of species good seed years are irregular and infrequent.
- The growth of the volume actually commercialized (VAC) for mixed forests is between 0.1-0.5 m^3/ha/year.
- The gross annual allowable cut (AAC) for intensively managed broadleaved forest is often estimated at between 0.5-1.0 m^3/ha/year, but can reach or surpass 2 m^3/ha/year.
- Logging intensities (America 8 m^3/ha/entry; Africa 13 m^3/ha/entry; Asia dipterocarp 40-100 m^3/ha/entry but the overall average is 37 m^3/ha/entry).
- Logging has become mechanized and large machines are used, with inadequate supervision and control.
- The damage to advance growth is the most serious since it affects an often very limited number of individuals that, on release from crown competition, have great growth potential and represent the next commercial crop from a given area.
- Today it is a common occurrence to find 40-70% of the advance growth destroyed in the harvesting process, leaving only between 12-33 stems/ha for the next cut.
- Damage to advanced growth consists mainly of crown break, which can be significantly reduced if lianas are cut some time in advance of felling, and stem and butt bark scraping, the damage done to regeneration is mostly caused by the passage of machines opening skid trails for log haul and preparing landings.
- In 1958, 14% of the coupe area was bared by logging operations in Insular Malaysia, while in 1965 the area bared was estimated to be 40% (dipterocarps do not regenerate on bared soil and there are the added problems of soil compaction, and disrupted water flow patterns.

- Very heavy damage (70-100%) can be expected when basal area extracted rises above 12 m^2/ha and there is poor control over logging operations and careless handling of large machinery.
- General reduction in damage through more careful control of operations and handling of the machinery, pre-logging treatment of the stand (vine cutting), better overall planning of the harvesting operations and by paying more attention to the training of machine operators.
- The operational methods used in harvesting tropical mixed forests have so far usually been designed to keep the cost of harvesting as low as possible and so-called silvicultural systems were often developed as a direct function of those methods.
- Although much has been written on tropical silviculture, the fact remains that comparatively little is known of the silvicultural requirements of many of the species in the tropical mixed forest, and as to how this forest can be managed on a sustained yield basis.
- Even in the more intensively logged dipterocarp forests, only 30% of the total volume is actually commercialized.

Matelson, T.J., Nadkarni, N.M. & Salano, R. 1995 Tree damage and annual mortality in a montane forest in Monteverde, Costa Rica. *Biotropica* 27(4): 441-447.
- 1403 live trees (742 10-30 cm dbh, 661 >30 cm dbh) on a 4 ha research area tagged.
- Over 4 years 147 trees were severely damaged over the four years.
- Mean number of damaged and dead trees was 15.9 trees/ha (9.9 in 10-0 cm dbh class and 6.0 in >30 cm dbh class) or 2.8% of tagged trees per year.
- Of the 147 trees damaged, snapped or fallen, 116 were dead (i.e., did not sprout new growth).
- The mean annual mortality was 12.7 trees/ha (s=5.9) (8.2 for 10-30 cm dbh and 4.6 for >30 cm dbh).
- Annual true mortality of 2.2% (2.1% for 10-30 cm DBH, 2.8% for >30 cm DBH).
- Turnover time was calculated as the number of years necessary for all of the originally inventoried trees to die [# of originally tagged trees/(# of dead and snapped trees/time observed)] (Uhl 1982).
- For 10-30 cm DBH the turnover time was 55.5 years, and for >30cm DBH it was 42.4 years.
- The 2.2% annual mortality rate is mid-range of annual mortality rates of other tropical forests (1-3% as published in Putz & Milton 1982, Uhl 1982, Brown et al. 1983, Lang & Knight 1983, Higuchi 1987, Manokaran & Kochummen 1987, Hartshorn 1990, Lieberman et al. 1990, Swaine et al. 1990 - of which most are from lowland tropical regions).

Mattsson-Marn, H.G. 1982 *The planning and design of the forest harvesting and log transport operation in the mixed dipterocarp forest of Sarawak. Food and Agriculture Organization of the United Nations, FO:MAL/76/008, Field Doc.* No. 17. 76pp.
- Report describes the system of logging in use, as well as the situation of forest engineering in Sarawak in 1978.
- Recommends the use of large scale topographic maps for planning roads and skid trails, the opening of the trails prior to felling, direction felling toward the skid trails, and the use of chokers and logging arches for skidding.
- Recommends strengthening the Forest Department for improved planning, construction and control of road construction, as well as logging operations on a whole, and that the long-term licensees also be fully responsible for planning the harvesting operations and road networks, and that they employ a sufficient number of adequately trained staff for such operations.
- In the mixed dipterocarp hill forests the average tree size is 5-6 m^3/stem and 60-80 cm dbh (generally varies from 45 to 140 cm dbh, with a maximum of 200 cm; but most big trees are hollow); the minimum felling limit is 45 cm dbh; potential net industrial volume (all species >46 cm dbh) 131.4 m^3/ha, however, only 28.7 m^3/ha is the actual yield (Field Doc. 4).
- With better planning of roads and logging operations, access will improve, and damage and wastage will be reduced.
- Report outlines the logging operations which are basically unplanned and uncontrolled, resulting in considerable operational inefficiencies and damage to residuals and the site, as well as damage to the logs.
- A serious problem facing the logging industry in the mixed dipterocarp forest in Sarawak is the almost complete lack of trained personnel in all categories, a problem which hinders the development of sound and economical operations.
- Report outlines the results from two case studies already presented in other reports (e.g., Mattsson-Marn and Jonkers 1981, Mattsson-Marn et al. 1981).
- The situation in 1981:
    - eight companies have sent personnel to the Logging Training School
    - two companies were making detailed planning maps, while four others were starting such activities
    - many licensees are changing from square cut block boundaries to boundaries which follow the natural terrain features

- most companies were supplied with 1:25000 aerial photographs of their areas
- one company started to use a highlead/skyline system, while four companies were using FMC steel tracked skidders, and two companies were using chokers and one company a logging arch on crawler tractors

Mattsson-Marn, H.G. & Jonkers, W. 1981 *Logging damage in tropical high forest. Food and Agriculture Organization of the United Nations, Project FO:MAL/76/008, Working Paper* No. 5. 15pp.

- Review of two studies carried out in the mixed dipterocarp hill forest in Sarawak.
- First study compared current logging practice (122 ha, logging intensity 53 m^3/ha) with planned RIL (122 ha, logging intensity 55 m^3/ha) (with RIL overall damage to residuals reduced by 50%, skidding efficiency increased by 36% (20 m^3/h vs. 14.7 m^3/h) and there was no cost increase with directional felling).
- In the current system trees are felled in the direction convenient to the feller and thus are scattered at random over the block. Skid trails go from log to log, and thus are long, steep and winding (sometimes completing a full circle) with sharp curves. As a result the skidding tends to be slow and damages to logs and the residual stand are excessive.
- Skidding costs in planned operation (including planning, opening up trails, supervision and skidding) was M\$4.56/m^3 (M\$0.24/m^3+M\$4.32/m^3), compared to M\$5.94/m^3 for the current system.
- The cost of preparing the topographic map was M\$0.23/m^3, but most of this charge should be against road building and not skidding.
- Tree gaps in planned 17.1% of area, while in current operations 30.4%.
- Both systems had 10.4% of area with bare soil (landings and skid trails).
- Planned operation 13.3 trees/ha uprooted and 13.8 trees/ha broken.
- Current operation 25.8 trees/ha uprooted and 22.5 trees/ha broken.
- Minor damage slightly more in the planned block.
- Found that 11 m^3/ha (20% of a total volume of sound timber felled of 55 m^3/ha) of logs that had been felled and bucked could not be located by the skidding crew and were thus abandoned vs. 5.5 m^3/ha in the planned block.
- Second study compared logging intensities of 10 m^3/ha (2 trees/ha), 32 m^3/ha (6.25 trees/ha) and 55 m^3/ha (13.3 trees/ha).
- Area occupied by skid trails and landings the same, while temporary opening space increased from 5% to 30% through the range of logging intensities.
- Under current logging practices some 60 trees/ha (or 40% of growing stock left after logging) of desirable species are destroyed in logging 55 m^3/ha, compared to an estimated 20-30 trees/ha in lightly logged areas (although in the study the lowest intensity had 10 trees/ha destroyed).
- The need to improve the standard of planning and execution of logging operations in the mixed dipterocarp hill forest is stressed, not only from the viewpoint of reducing the loss of actual and potential raw material, but in order to ensure the perpetuation of the forest as a viable entity.
- Found in studies in MDF in Sarawak that if selectively logging forest is treated immediately after logging so that sound stems of desirable species are released from competition, the logging cycle can be reduced and the harvestable volume for the next cut will not be less than the first cut.
- About 4.4% of the area logged is covered by secondary (40 m^2/ha) and feeder roads (400 m^2/ha).
- Need proper control of operations by trained supervisors.

Mattsson-Marn, H., Vel, E., de Jongh O. & Hui, D.C.K 1981 *Planning and cost studies in harvesting in the mixed dipterocarp forest of Sarawak: Part I. Based on maps derived from ground survey. Food and Agriculture Organization of the United Nations, FO: MAL/76/008, Field Document* No. 7. 76pp.

- Study of logging operations in a mixed dipterocarp forest in Sarawak, Malaysia.
- Planning entailed: 1) topographic survey and preparation of large scale topographic maps (1:3000) with contour interval of 5 m; planning the road and skid trail network and logging blocks on these maps; and 3) aligning the roads, trails and blocks on the ground.
- Also used direction felling to fell trees towards prepared trails to facilitate skidding and minimize damage to the remaining stand.
- In the planned area the crawler tractor was equipped with two chokers on a mainline.
- The planned operation with directional felling was compared to a conventional operation with no planning, no directional felling and a crawler tractor not using chokers.
- In the planned operation, skidding efficiency increased 36%, overall damage to the forest was reduced by 33%, 50% less volume of felled sound timber was left in the forest, and no trees were split during felling.
- This was achieved with no increase in felling cost, but rather with a reduction in cost of 23%.
- The total cost for planning of main skid trails, opening up trails, supervision and skidding was \$4.56/m^3 (Malaysian dollars), compared to \$5.94/m^3 for traditional skidding.

- The skidder operator in the planned area was not as experienced as the other, thus, it was estimated that production could have been increased by 70% (versus 36%) if similar skilled operators had been used.
- If the $0.23/m^3 cost for making the topographic maps is included the cost advantage is reduced to 19% in favour of planned harvesting.
- Planning and opening of trails prior to felling is a basic requirement for an efficient logging operation, as is the large scale topographic map that made the planning possible.
- To be fully effective the planned logging operation must be supervised constantly by trained supervisory personnel (included in above costs).
- The area was covered by a regular road pattern consisting of one secondary road and five almost parallel feed roads nearly perpendicular to the secondary road (4 km of secondary road (6.25 m/ha), 7.0 km of feeder road (11 m/ha)), for a total road density of 17.25 m/ha.
- Overall costs involved in topographic survey and planning of roads and skid trails ($ are Malaysian currency units):

	$ per ha	**$/m^3 (logging intensity =54 m^3/ha)**
Cost of topographic survey including office work	12.68	0.23
Cost of road planning	6.59	0.12
Cost of planning of main skid trails	3.22	0.06
Total cost of survey and planning of roads and main skid trails:	22.49	0.41

- Assuming 4 m wide trails 5% of area covered by trails in planned and 7% in unplanned.
- Logging damage was only calculated for commercial species.
- Planned area had 17.1% of areas as temporary open space vs. 30.4% in unplanned.
- 13 trees/ha uprooted and 14 trees/ha broken in planned block vs. 26 trees/ha uprooted and 22 trees/ha broken in unplanned control area.
- Minor damage was slightly higher in the planned block (assuming 35% of trees with minor damage will die based on other research), thus, an additional 12 trees/ha in the planned and 11 trees/ha in the unplanned areas would be lost to mortality.
- The total number of trees lost are planned 40 trees/ha vs. unplanned with 60 trees/ha (33% less mortality).
- In the unplanned area 3.3 felled trees/ha were left in the forest (0.8 trees/ha showed extensive rot, 1.3 trees/ha were hollow and split during the felling operation, and the remaining 1.3 logs/ha contained 11.5 m^3/ha of sound timber.
- In the planned area 1.25 felled trees/ha were not or only partly extracted (none were split, two logs (0.8 logs/ha) were free of serious defects and could have contributed 5.5 m^3/ha).
- Summary of costs ($=Malaysian $, 1981)

	Unplanned logging ($/m^3)	**Planned logging ($/m^3)**
Topographic survey		+
10% inventory	0.14	0.32[1]
Road planning	0.12	0.12
Planning of main skid trails		0.06
Road construction	2.66[2]	2.66
Felling	2.31	2.29
Skidding	5.94	4.38
Supervision of felling & skidding		0.12
Loading	0.90	0.90
Road Transport	5.07	5.07
TOTAL DIRECT LABOUR & MACHINE	17.14	15.92
OTHER LABOUR COSTS	4.00	4.00
OVERHEAD COSTS (40%)	10.57	9.96
TOTAL COST	31.71	29.88

[1] The cost for a separate topographic survey is $0.23/m^3 and for a separate inventory $0.14, but when done at the same time it is estimated to be $0.32/m^3.
[2] The cost of constructing a road planned in the traditional way, to the same standard as was done in the planned area will actually be higher.

Mattsson-Marn, H. & Jonkers, W. 1982 Logging damage in tropical high forest. *In*: Srivastava, P.B.L. et al. (eds.). *Tropical Forests -- Source of Energy Through Optimisation and Diversification*. Proceedings of an international conference held 11-15 November 1980 at Penerbit Universiti Pertanian, Serdang, Selangor, Malaysia. p.27-38.

- Harvesting operations utilizing detailed planning cost 20-45% less than comparable operations with minimal planning.
- The study also found that better planning had better organization and supervision, fewer accidents, fewer merchantable trees left unfelled and few logs lost after felling.

Mauricio, F.P. 1984 Study cites environmental changes in selectively-logged Surigao forests: Parts I and II. *The Philippine Lumberman* 30(6 & 7): 7-13; 8-10,28.

- Study of logging in dipterocarp forests in rough terrain of Eastern Mindanao, Philippines.
- Uncontrolled removal of utilizable timber at the 10 to 15 years after logging caused excessive destruction to the residual stands.
- Highly mechanized operations with Berger and Washington Iron Works tower yarders.
- Continued decrease in stand density up to the third year due to mortality of damaged and exposed trees.
- Only 49.9% of the original stand was undamaged and non-defective after logging (based on stem numbers).
- 20.1% of original stand was naturally defective.
- 21.5% of original stand had logging damage.
- Assuming the difference of 8.5% was removed (original about 440 stems/ha).

McNabb, K.L., Miller, M.S., Lockaby, B.G., Stokes, B.J., Clawson, R.G., Stanturf, J.A. & Silva, J.N.M. 1997 Selection harvest in Amazonian rainforests: long-term impacts on soil properties. *Forest Ecology and Management* 93: 153-160.

- The study area is located in the Brazilian Amazon.
- The soil is a clayey Ferrasol, which is usually well drained, water permeable, and highly resistant to erosion.
- A single tree selection harvest of all commercial timber >55cm dbh and a selection harvest of all commercial species >45cm dbh were applied.
- An average of 16 trees/ha was harvested which translates to a volume extraction of 75 m^3/ha.
- The data from both logging intensities and from primary and secondary skid trails were summarised for analysis.
- Ruts and skid trails were still visible 16 years after harvest.
- 16 years after harvesting, 99% of the area were classified as minimally disturbed and 1% as skid trails.
- In general, concentrations of nitrogen [N], phosphor [P], potassium [K], and carbon [C] decreased with increasing disturbance intensity while those of calcium [Ca] and magnesium [Mg] increased.
- There were significant changes in bulk density, Ca and Mg concentrations between the controls and the minimally disturbed areas.
- Bulk density data indicated that soils remained compacted in all disturbance classes after 16 years.
- The tendency for Ca and Mg concentration to vary directly with disturbance intensity could be explained by increased weathering, increased mineralization or decreased plant uptake rates.
- Restricted rooting due to increasing bulk densities as disturbance increases could cause the decrease in organic N and C.
- Residual soil compaction might also contribute to reduced mineralization of P and K through reduced aeration and water holding capacity.

Megahan, W.F. 1977 Reducing erosional impacts of roads. *In*: *Guidelines for watershed management*. Food and Agriculture Organization of the United Nations, Rome, Conservation Guide 1. p.227-261.

- Experience by FAO in developing countries has often shown that roads are the major source of erosion.
- Effects vary considerably depending on the geologic, climatic, landform, soil and vegetation properties of the area or country in question and upon the care taken to reduce erosion in all phases of the road development project.

Meijer, W. 1970 Regeneration of tropical lowland forests in Sabah, Malaysia, forty years after logging. *Malaysian Forester* 33(3): 204-229.

- Average logging intensity in Sabah 1000 ft3/acre (=69 m^3/ha).
- Between 20-40% soil disturbance with heavy logging equipment.
- Area logged used highlead yarding.
- 40 years after logging dipterocarp volumes: logged plot (72 trees, 15 species, 18,884 ft^3 per acre) and unlogged plot (76 trees, 17 species, 34,273 ft^3 per acre).

- 40 years after logging the average dipterocarp volume per hectare is half of that of adjacent primary forest.
- For non-dipterocarp species (except iron wood): logged (26 trees, 22 species, 5834 ft^3 per acre); unlogged (17 trees, 16 species, 7853 ft^3 per hectare).
- A comparison of a heavily disturbed site near the spar tree with less disturbed forest yielded the following information per acre: heavily disturbed (7 dipterocarps 3-5 ft girth, 434 ft^3 per acre); less disturbed (15 dipterocarps 3-11 ft girth, 3296 ft^3 per acre).
- In the disturbed area the greatest volume (1354 ft^3/acre) is occupied by *Anthocephalus*.
- Average dipterocarp forest in Sabah can produce between 18-30 ft3/acre/year of millable (6 ft plus) timber over a period of 40 years (50-83 m^3/ha).
- A selective system of logging with marking trees for retention would be the best safeguard for a sustained yield of high productive tropical forest soils under a 60-80 year rotation.
- Areas of intensive soil disturbance can be traced back even 40-45 years.
- The normal species composition of mature forest has returned in the areas without soil disturbance where scattered mother trees (about 5/acre) were left.
- Species of trees left unlogged have not become more frequent than those that were harvested.
- Dipterocarp trees in girth classes 4-6 ft (20-30 cm dbh) and defective trees >6 ft girth (>30 cm dbh) should be left undisturbed in order to safeguard natural regeneration.
- Better to not open up the stand so that pioneer species invade the site and slow dipterocarp growth.

Mendoza, G.A. & Setyarso, A. 1986 A transition matrix forest growth model for evaluating alternative harvesting schemes in Indonesia. *Forest Ecology and Management* 15(3): 219-228.
- Transition matrix model constructed for tropical forests in Indonesia, managed under the Indonesian Selective Logging System (TPI) (east Kalimantan).
- TPI can support the second harvest, but shows that the system's 35-year harvest cycle is too rapid to sustain the current yield after it (e.g., when maintaining same harvest intensity and a 50 cm dbh diameter limit).
- Adjustments must be made to the second and succeeding cuts in order to proved sufficient growing stock for future harvests.
- TPI requires 25 residual trees/ha with a 35 year cutting cycle and 50 cm dbh cutting limit, while the model indicates that 50 residual trees/ha are required.
- The optimal TPI harvest intensity for the case study company forest was 67.3 m^3/ha, while the company actually harvested 85.8 m^3/ha.
- When the cutting cycle was reduced to 25 years, while retaining a 50 cm dbh cutting limit, the optimal harvesting intensity was reduced to 51.9 m^3/ha.
- When harvesting 60% of trees in dbh class 40-60 cm, 80% in 60-70 cm dbh class and 100% of trees >70 cm dbh on a 35 year cycle, the optimum logging intensity was 71.9 m^3/ha.

Miller, T.B. 1981Growth and yields of logged-over mixed dipterocarp forest in North Borneo. *Malaysian Forester* 44(2-3): 235-245.
- Net growth rate per hectare per year as a function of logging severity for eight plots in logged over forest (logging severity = % of original stems cut, damaged and destroyed per plot):

Logging severity, %	Number of years since logging	Net growth rate, m^3/ha/year
4	7	3.9
9	7	5.9
10	7	3.4
15	7	4,9
20	7	0.8
23	7	-1.7
36	2	-2.4
76	2	-16.3

- Mean diameter growth rates of undamaged trees 6 years after logging and similar trees in a virgin stand:

Dbh class, cm	Mean diameter growth, cm/year			
	Virgin Forest	Logging severity		
		4%	15%	20%
15-24.9	0.2	0.4	0.4	1.6
25-34.9	0.6	0.4	0.6	1.2
35-44.9	0.7	0.4	1.0	1.6

- Differences in net growth rates for the plots indicate that cutting cycles will vary considerably over the concession; some areas will have replaced the volume removed in less than 5 years, in other areas regrowth will take considerably longer than 40 years.
- This preliminary analysis suggests that 2-3 m^3/ha/year net growth rate after logging is achievable (compared to their plantation growth rates of 12-20 m^3/ha/year).

Mohd Shahwahid, H.O., Awang Noor, A.G., Abdul Rahim, N., Zulkifly, Y. & Tazuni, U. 1999Trade-offs among competing uses of Malaysian forested catchments. *Environment and Development Economics* 4: 279-311.

- Costs and benefits of three land use options (catchment protection [CP], conventional logging [CL] and reduced impact logging [RIL]) were evaluated for catchments in Selangor, Malaysia.
- A water regulatory dam and three regulatory dams are located within the study area.
- Harvesting intervals range from 30-35 years, with cutting limits no lower than 50cm dbh for dipterocarp and 45cm dbh for non-dipterocarp timber species.
- For both the RIL and the CL option the net timber yield is 49.3 m^3/ha for the first cutting cycle and 31.6 m^3/ha for the second cutting cycle.
- Residual stocking minimum is 32 trees/ha of commercial species of good quality from diameter class 30-45cm or its equivalent.
- For RIL a 20m wide buffer was designated along streams, for CL the buffer was reduced to 5m width.
- Studies by Rahim (1998) and Baharuddin (1988 and 1995) have revealed that the rate of sedimentation tends to recover five years after logging operations provided that no further encroachment occurs in the logged area.
- RIL can significantly reduce the amount of sedimentation by imposing further control measures such as better road planning, and monitoring and enforcement of forest management specifications. Therefore a yield reduction factor of 0.6 was assumed for RIL operations when compared to conventional harvesting practices.
- Costs and revenues of timber production (US$ 1 = RM 3.80 [1998]):

	Catchment Protection	Reduced Impact Logging [US$]	Conventional Logging [US$]
Revenue	-	4,195,731	4,918,140
Direct logging cost	-	1,676,286 (83.4%)	1,964,905 (83.7%)
Rehabilitation cost	-	71,620(3.6%)	122,867 (5.2%)
Administration and management cost	-	261,307 (13.0%)	261,307 (13.0%)
Total cost	-	2,009,213 (100%)	2,349,080 (100%)
Net present value	-	2,186,517	2,569,060

- The higher logging and rehabilitation cost of timber production under the CL option significantly reduces its net present value compared to RIL operations.

- Costs and revenues of treated water production:

	Catchment Protection	Reduced Impact Logging [US$]	Conventional Logging [US$]
Revenue	7,651,629	7,651,629	7,651,629
Direct production cost	2,652,246 (82%)	2,652,246 (82%)	2,652,246 (82%)
Treatment cost	582,326 (18.0%)	1,897,616 (41.7%)	2,760,688(51%)
Total cost	3,234,573 (100%)	4,549,831 (100%)	5,412,934 (100%)
Net present value	4,417,056	3,101,767	2,238,695

- Costs and benefits of hydro-electric power production:

	Catchment Protection	Reduced Impact Logging [US$]	Conventional Logging [US$]
Revenue	5,914,259	5,914,259	5,914,259
Production cost	4,480,499 (98.3%)	4,480,499 (98.3%)	4,480,499 (98.3%)
Production losses	70,339 (1.5%)	430,467 (8.7%)	754,165 (14.2%)
Maintenance cost	8,551 (0.2%)	198,828 (1.0%)	91,716 (1.7%)
Total cost	4,559,389 (100%)	52,323 (100%)	5,326,380 (100%)
Net present value	1,354,870	950,969	587,879

- Net present value of the three land use options:

	Catchment Protection [US$]	Reduced Impact Logging [US$]	Conventional Logging [US$]	Incremental Net Present Value (RIL->CP) [US$]	Incremental Net Present Value (CL->CP) [US$]
Sub-total timber	-	2,186,517	2,569,059	+2,186,517	+2,569,059
Treated water	4,417,056	3,101,767	2,238,695	-1,315,288 (-29.8%)	-2,178,361 (-49.1%)
Hydroelectric Power	1,354,870	950,969	587,879	-403,900 (-29.8%)	-766,990 (-56.6-5)
Sub-total water	5,771,926	4,052,736	2,826,574	-1,719,189 (-29.8%)	-2,945,351 (-51.0%)
Net present value	5,771,926	6,239,254	5,395,634	+467,328 (+8.1%)	-376,292 (-6.5%)

- The efficient choice among the two logging methods is the RIL option owing to the higher returns and the lower externality imposed upon the status quo water users.
- The returns from timber cannot meet that from the status quo production of treated water under both logging methods. However, complementing water uses with logging in forested catchments is efficient where hydroelectric power is produced.
- These findings cannot be extended to other forest catchments without making adjustments to the numerical results, such as incorporating different rates of sedimentation, rainfall and sediment concentration.
- Future studies should consider using shadow prices instead of negotiated prices for treated water and hydro-electric power by estimating the marginal costs of production in a new hydro-electric power plant or water treatment plant or of alternative power plants and production of treated water from alternative sources such as groundwater.

Mok, S.T. 1992 Potential for sustainable tropical forest management in Malaysia. *Unasylva* 43(169): 28-33.

- The MUS has been substantially modified over time with a shift toward more selective felling and the retention of advance growth as well as a more discriminating use of poison girdling as a silvicultural tool.
- Integrated studies in forest management operations in Peninsular Malaysia show that with average annual growth rates of 0.8 to 1.0 cm in diameter and 2 to 2.5 m^3/ha in gross commercial volume for trees of more than 30 cm dbh, about three-quarters of the hill forest is capable of producing at least 40 to 45 m^3/ha every 30 years - this is about the current average outturn of the virgin hill forests.
- Growth and yield studies in Sabah and Sarawak have shown similarly positive results.

Mori, S. 1992 An example of sustainable forest management in West New Britain Island of Papua New Guinea. *In*: *Beyond the guidelines - an action program for sustainable management of tropical forests. International Tropical Timber Organization, Technical Series* No. 7. P.157.

Species	Cutting cycle years	Size of tree		Standing volume m^3	Harvest volume m^3	Uses	
		Height, m	DBH, cm			Sawn/ply	Pulp
Eucalyptus deglupta	20	50-60	70-75	400-500	300-400	OK	OK
Octomeles sumatrana (Ertma)	15	40-50	80-85	400-500	300-400	OK	Not suitable
Terminalia b.	20	50	70-75	400-500	300-400	OK	Not suitable
Tectona grandis	25	40	65-70	400	300	OK	OK

Moura-Costa, P. 1997 Reduced impact logging techniques as a means for carbon offsets. *In*: *Proceedings of the FAO/IUFRO Satellite Meeting held in conjunction with the IUFRO XX World Congress*, Tampere, Finland, 4-5 August, 1995, Research on Environmentally Sound Forest Practices to Sustain Tropical Forests. Food and Agriculture Organization of the United Nations. P.37-45.

- RIL experiment in Sabah, Malaysia.
- 8-15 trees/ha (80 m^3/ha) normally extracted in logging in E. Malaysia, which can result in up to 50% of the residual stand damaged and up to 40% of the area crushed by bulldozers.

- Uncontrolled logging has a severe impact on biodiversity and ecosystem function, and leads to increased soil erosion, weed infestations and incidence of fire.
- These effects combine with the destruction of much of the pre-existing regeneration of commercially valuable trees to make uncontrolled logging extremely detrimental to long-term ecological and economic productivity.
- Training needed at all levels of the hierarchy - from tree fellers to senior management.
- In conventional logging bulldozer traversed area can be up to 30-40% of the area.
- RIL reduced the area of log landings by 50%.
- Figures of logging impacts after harvesting of 120 m^3/ha in hilly area in Sabah following RIL (reduced impact) and CNV (conventional) logging from ca. 800 ha:

	Reduced impact logging	**Conventional logging**
Roads	20 m/ha 1.6% of logged area	24 m/ha 3.3% of logged area
Skid trails	71 m/ha 4% of logged area	205 m/ha 13% of logged area
Log landings	57 m^2/ha	103 m^2/ha
Residual trees damaged	29%	56%

- In the initial analysis the operational costs of RIL are higher than those of conventional logging due to the extra activities required (detailed inventories, training, climber cutting, intensive supervision).
- However, after the initial phase of learning and intensive training it is expected that RIL operations will run more smoothly and efficiently than in conventional logging.
- This may lead to savings through reduced use of bulldozers, with lower fuel and maintenance costs.
- Added benefit of a sense of pride in the logging crews and field staff.
- Training of the logging crews has triggered a positive catalytic effect on the logging attitude around the region (professional pride and competition has led to an unexpected improvement of the performance of other logging crews operating in the ICSB's concession).

Muladi, S. 1996 Quantification and use of dipterocarp wood residue in east Kalimantan. *In*: A. Schulte and D. Schöne (eds.). *Dipterocarp Forest Ecosystems: Towards Sustainable Management*. World Scientific Publishing Co. Pte. Ltd., Singapore. p.603-615.

- Since 1981, when the Indonesian government blocked round wood exports, followed by a total ban in 1985, 2708 sawmills and 117 plywood mills have been built.
- The large and medium size mills are concentrated in Kalimantan (59.3%), with about 23% located in east Kalimantan.
- Logs produced accounted for 63.2% of the felled trees, with residue being 36.8% (stump 5.3%, buttress 3.8%, defective logs 6.0%, branches 21.7%).
- Logging intensity was 5.2-6.9 trees/ha (42-67 m^3/ha) extracted for four logging sites totaling 130 ha.
- Sawmill recovery rate was 50% and residue 35% by volume for logs received at the mills.
- Plywood conversion efficiency was 42-65%, with an average rate of 55%.

Muñoz, R.R. 1997 *Costo de la regencia para el aprovechamiento forestal*. Colegio de Ingeniores Agrónomos de Costa Rica.

- This study was carried out in Costa Rica, where the commercial timber value ranges from 90 to 1712m^3/ha.
- Average labour costs are US$ 2.39/m^3.

- Average costs for forest utilisation in Costa Rica:

	US$/$m^3$	**%**
Value (per m^3 of wood)	37.80	47.02
Management Plan	2.99	3.72
Regency	0.58	0.72
Utilization	21.16	26.32
Sub-Total	62.53	77.78
Profit (30%)	17.86	22.22
Total	80.39	100.00

- Distribution of the management costs:

	US$/$m^3$	%
Honorarium	69.11	53.33
Transportation	22.67	17.49
Travel allowances	15.12	11.67
Office	7.56	5.83
Procedures	15.12	11.67
Total	129.58	100.00

Munoz-Braz, E. & d'Oliveira, M.V.N. 1996 Planning to Reduce Damage. *ITTO, Tropical Forest Update* 6(3).

- This article examines the planning undertaken within the context of the ITTO funded project 'Integrated sustainable development of the Western Amazon based on resources'.
- Three levels of harvesting are proposed and local people will be trained to carry out the harvests.
- The first two levels will prepare them to consider the logistical, technical, social and economic implications of the third level.

Mussong, M., Singh, K., Laqeretabua, J. and de Vletter, J. 1996 Ökonomische Auswirkungen unterschiedlicher Nutzungsintensitäten in tropischen Regenwäldern Fidschis. *Forstarchiv* 67: 82-87.

- Criteria for conventional exploitation and modified logging intensities:

Criteria	**Conventional logging [CL]**	**Reduced Impact Logging (Harvesting Intensity)**		
		High [HL]	**Medium [ML]**	**Low [LL]**
Number of target diameter classes	1	3	4	5
Minimum target diameter	35	35-60-100	35-50-75-105	40-50-65-80-110
Harvesting intensity (% of volume >35cm dbh)	_80	50-60	30-40	15-20

- Reference values for the various logging intensities:

	CL	HL	ML	LL
Performance (timber harvesting)				
Roads (m/m^3)	0.30	0.20	0.39	0.94
Skid trails (m/m^3)	3.35	2.38	5.13	8.86
Felling (m^3/day)	20.48	23.92	25.97	16.95
Skidding (m^3/day)	18.00	19.28	20.97	22.32
Bucking (m^3/day)	64.71	89.00	117.48	88.93
Loading (m^3/day)	24.24	33.41	43.84	33.91
Transport (m^3/day)	5.14	5.14	5.14	5.14
Management activities				
Planning and supervision (h/ha)	5.5	10.2	9.4	8.8
Layout of harvesting units (h/ha)	-	3.0	3.0	3.0
Inventory (h/ha)	-	13.0	13.0	13.0
Selection of trees for harvest (h/ha)	-	13.3	11.4	10.0

Data from the study sites:

	CL	HL	ML	LL
Area harvested (ha)	42.3	35.5	56.6	41.8
Stand volume (m^3_ 35cm dbh)	3084	5811	7306	5000
Harvesting intensity (m^3)	2517	3309	2824	858
Volume sold (m^3)	1741	2198	1797	542
Average stem volume (m^3)	1.51	1.94	3.18	3.84
Overall costs				
Harvesting (US$/$m^3$)	27.99	24.83	24.33	28.06
Fees and Taxed (US$/$m^3$)	10.65	11.44	11.28	9.84
Management (US$/$m^3$)	0.20	1.15	1.67	3.08
Sum	38.84	37.47	37.29	40.98

- Assumed felling cycles:

Treatment	**Cutting cycle (years)**		
	Optimistic	**Realistic**	**Pessimistic**
CL	35	45	55
HL	20	30	40
ML	10	15	20
LL	6	10	15

- Profit calculation for the various management options:

Treatment	**Expenses (US$/$m^3$)**	**Income (US$/$m^3$)**	**Revenue (US$/$m^3$)**
CL	39.64	36.13	-2.51
HL	36.27	36.18	-0.10
ML	35.62	36.35	+0.73
LL	37.90	36.75	-1.15

- The most favourable management concepts are HL and ML. These options also ensure that non-timber forest products can be produced on a sustainable basis.
- In order to minimise risk, the ML option seems to be most favourable, because it minimises the impact on the residual stand without compromising economic aspects.

Myers, N. 1983 Tropical moist forests: over-exploited and under-utilized? *Forest Ecology and Management* 6(1): 59-79.

- The great bulk of tropical moist forests are located in a belt that receives almost half the planet's rainfall on land, but only occupy about 7% of the land surface.
- The impact of tropical downpours causes substantially more soil erosion than anywhere else in the world; e.g., eroded areas in Indonesia exceed one-fifth the national territory.
- Current harvest patterns correspond , in their haphazard form, to hunter-gather types of agriculture - thereby offering much scope for rational and systematized expansion.
- Since we know less about the workings of TMF ecosystems than we do about any other biome on earth, we need to adopt a cautious approach to our use of them.

Natadiwirya, M. & Martikainen, M. 2002 The financial benefits of reduced impact logging: saving costs and the forest – a case study from Labanan, East Kalimantan. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- P.T. Inhutani I is an Indonesian state forest enterprise managing forest concessions located in several regencies in East Kalimantan and covering a total forest area of 1.1 million ha.
- Three logging methods were studied at an operational scale, covering 237 trips extracting 1 500 m3 of timber from three compartments.
- Compartment A was logged using a bulldozer and RIL techniques.
- Compartment B used RIL techniques and a combination of a bulldozer and a wheeled skidder.
- Compartment C was logged using conventional bulldozer techniques.
- Successful implementation of RIL is based on improved planning of harvest operations. ▪ Reliable tree and topographic data for the compartments to be harvested are required.

- The results indicate that environmental damage is much lower under RIL than CL.
- The skid trail area opened in CL areas was 1.7 times that of skid trails in the RIL compartment.
- Cross-slope trails and cutting depths were also greater in the conventional plots, increasing soil disturbance and machine time.
- The results indicate that log production costs are much lower under RIL than CL.
- Bulldozer hours for skid trail construction were 2.8 times higher in a conventionally harvested compartment than in the compartment harvested under RIL.
- The total cost of bulldozer skidding in a well-planned compartment applying RIL was only 67 percent of the cost of CL, mainly because of lower skid trail construction costs and avoidance of delays, both resulting from better planning.
- For a standardised compartment (100 ha with 3000 m^3 timber extracted) under CL, the total costs were Rp154 million, and an estimated 48 days were required to log the compartment.
- A bulldozer using RIL techniques completed the same work in 32 days at a total cost of Rp 103 million.
- The combination of wheeled skidder and bulldozer completed the work in 30 days at a total of Rp 94 million.
- The additional cost of improved planning required to execute RIL is estimated at Rp 4 million per 100 ha compartment.

Neil, P.E. 1984 Climber problems in Solomon Islands forestry. *Commonwealth Forestry Review* 63(1): 27-34.
- As the intensity of logging increases, the decrease in shading allows climber species to become the dominant vegetation.
- During the 1960's and early 1970's logging was more selective and soil damage by extraction affected 10-15% of the area and the canopy was broken in places but by no means removed.
- In the late 1970's, with the increase in number of species utilized and acceptance of small logs, logging became increasingly intensive and became essentially a clearfelling with up to 70% of the area disturbed or compacted.
- The result was a massive invasion of climbers that choke out the natural regeneration and planted trees.
- In one example, nine maintenance operations were required annually to control the climbers and the cost of these operations was considerable.
- In larger gaps climber infestations can remain the dominant vegetation log after logging operations have ceased.

Nguyen-The, N., Favrichon, V., Sist, P., Houde, L., Bertault, J.G. & Fauvet, N. 1998 Growth and mortality patterns before and after logging. *In*: *Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantan*. Cirad-foret, France.
- In primary forest, the overall annual mortality rate was 1.5% in number of stems (9 stems/ha*year; 0.57 m^2/ha*year).
- The mortality was calculated based on three harvesting intensities (low impact logging with remaining basal area _80%, intermediate with remaining basal area between 70 and 80% and high impact logging with remaining basal area _80%).
- The mortality after logging was 2.5% per year, no differences could be detected between the three logging treatments over a period of 2 years.
- The drastic reduction of damages obtained with RIL methods during the harvesting process did not result in a significant reduction of the subsequent mortality.
- The injured trees composed 26% of the residual stand and they constituted 51% of the trees that died during the following 2 years.

Nicholson, D.I. 1958a Natural regeneration of logged tropical rain forest, North Borneo. *Malaysian Forester* 21(2): 65- 71.
- Soil disturbance by tractor trails bare of regeneration averages 14% of area.

Nicholson, D.I. 1958b An analysis of logging damage in tropical rain forest, North Borneo. *Malaysian Forester* 21(4): 235-245.
- 53% of residual trees were damaged.
- Fallen and broken off trees 30%, bark damage 11%, crown damage 4%, for total damage 45%.
- Trees with little damage 8%, undamaged trees of good form 35%, undamaged trees with poor form 12%, for 55% little or not damaged.
- The volume extracted was 4.7 trees/acre (1308 hoppus ft^3/acre) = 116.5 m^3/ha @ 11.6 trees/ha removed.
- The amount of damage to residuals increases with logging intensity.

- Shown that even with an average of 45% of the stand damaged, there remain about 20 trees/ha between 10-60 cm dbh which have suffered no damage and which could yield a stand as good or better than the one just logged.
- However, the above analysis does not take into account trees felled during roading or felling.

Nicholson, D.I. 1965 A review of natural regeneration in the Dipterocarp Forests of Sabah. *Malaysian Forester* 28(1): 4-26.
- To get dipterocarp regeneration need a sufficient number of seedlings in the area after logging.
- One should always find a large number of dipterocarp seedlings on the ground before logging, although there are exceptions.
- There is a general tendency for the intensity of logging to increase with the passage of time and for tractor damage to increase.
- The 14% of bared area in typical logging areas given by Nicholson (1958) is now very often exceeded and figures as high as 40% have been estimated.
- Though some rise is probably inevitable, it is not conceded that tractor damage must rise in proportion to the intensity of logging.
- Growth response of undamaged trees after logging (rate still increasing in logged areas):

	Size class, feet (dbh)					
	1	**2**	**3**	**4**	**5**	**Mean**
CAI before logging, in.	0.35	0.57	0.60	0.66	0.64	0.50
CAI 1-year after logging, in.	1.08	1.56	1.80	0.87	1.49	1.36
Number of trees/acre	2.4	1.5	1.0	0.7	0.9	6.4

- It cannot be too strongly stressed that a well-regenerated forest depends on a careful logging operation.
- Only extraction has the potential to reduce the regenerating forest to a mass of useless weeds, by destroying existing seedlings and poles.
- The most destructive damage appears to stem from inefficient use of tractor tracks, widening of tractor tracks to avoid boggy areas, and large collection points near loading points (landings).
- Much damage to poles could be avoided by considerate use of the dozer blade and by ensuring that the logs on haul do not debark or shatter the roots of young commercial trees.
- The use of the tractor winch and cable would lessen tractor-logging damage.

Nicholson, D.I. 1979 *The effects of logging and treatment on the mixed dipterocarp forests of Southeast Asia*. Food and Agriculture Organization of the United Nations, Rome, Rep. FO:MISC/79/8. 65pp.
- Increasing impact of logging, probably due to a reduction in quality of supervision and training following the end of the colonial period, increased use of mechanized equipment (as opposed to manual methods or animal skidding), careless handling of machinery by unskilled operators, and increasing reliance on horsepower rather than on technical competence.
- Costs are not dealt with critically, but avoidance of logging damage is seen as a very necessary and satisfactory way of increasing yield under present conditions.
- Limiting tractor or cable damage and marking for felling and retention are seen as practical ways of doing this.
- Selective logging is seen as a workable system, given better control of logging.
- Need for prior inventory data is stressed (deal with problems areas and provide a basis for residual marking).
- In the late 70s the literature on the situation in the late 50s and 60s was still applicable; logging intensities were still very much the same, though very variable.
- Most of the growth data from yield plots indicate very rapid seedling and sapling increment, e.g. 1.9 cm/year in diameter growth in 4-year-old regeneration (dipterocarp need direct sun for rapid growth).
- Important to retain sufficient advance growth after logging to ensure sustainability.
- In the Philippines it is of interest that the felling limits set in 1973 approximate very closely to a simple 70 cm limit, for average diameter distribution. It is agreed that some cutting in the 55-65 cm size could be beneficial but unless closely watched, abuses such as taking the best 25% rather than the worst, could occur.
- Dipterocarps need a heavy logging and then a long period of closure as can be provided by a bi-cyclic system. However, it may be necessary to impose limits on the first cut in the interest of those that follow.
- In the late 1950s about 14% of the area was bared by tractors, while in the 1970s >40% was being bared.
- Dipterocarps do not regenerate well on bared soil and it may be 10-15 years before tractor tracks become similar to undisturbed areas.

- It cannot be too strongly stressed that a well regenerated forest depends on a careful logging operation.
- Much higher commercial MAI with longer logging cycles (e.g. in Philippine untreated stand case studies, a 30 year cycle 1.6-2.8 m^3/ha/year, while a 40 year cycle 2.0-3.5 m^3/ha/year).
- It is reasonable to use a minimum figure of 1 cm/year diameter growth for all sizes and the error if any, would be on the safe side; for silviculturally treated stands a minimum value of 1.25 cm/year can be used.
- It seems quite clear that even with the low degree of control being exercised over logging that a significant volume can be obtained after 30 years from felling. Any improvement in logging practice that preserves more of the advance growth must have a marked effect on this intermediate yield.
- The treated volume at 40 years is about 80 m^3/ha (@ 1.25 cm/year diameter growth).
- Andel (1978) shows from one example that proper logging control in West Malaysia may add M$51-70/ha, whereas a post logging silvicultural treatment (including planting of roads and landings) may cost about M$200/ha.
- Even if more nearly equal, the repair of a bad logging operation by post-logging treatments must be more expensive when one considers the only available replacement for a destroyed tree, is a seedling which will take so much longer to produce saleable wood.
- Therefore, though it can be shown that advance growth is greatly benefited by freeing from competing trees, the preservation of the tree in the first place is of more vital importance.
- Too short a cutting cycle will have very serious effects on yield, if not on permanence of the dipterocarps themselves. Even the 40 year cycle suggested here may have to be lengthened if significant seeding does not occur by this time. Certainly very short pulpwood rotations in conjunction with enrichment with fast growing species cannot be considered in dipterocarp management since no seeding at all will occur.
- Area destroyed by tractors needs to be limited to a maximum of 20-25%.
- Selective logging is recommended wherever there is sufficient advance regeneration present, otherwise some sort of MUS with planting is required.
- Philippines - the logging cycle should be about 40 years.
- Sabah - due to excessive logging and stand damage in the past a 60 year cycle will be needed to get the stands back into better shape, after which a 40 year cycle could be used.
- Sarawak - 40 year cycle is recommended, but believes the current 45 cm diameter cutting limit is too low.
- West Malaysia - due to problems with inventory and logging, a 60 year cycle is recommended. Again like in Sabah, it should be possible to go to a 40 year cycle once the forest becomes stable.
- Indonesia - 40 year cycle with a minimum yield of 2 m^3/ha/year is possible when silviculturally treated.

Niedermaier, P. 1984 Plywood substitutes urged for maximum forest utilization: Parts I and II. *The Philippine Lumberman* 30(7 & 8): 11-16; 8-13,30.
- Product yields on round wood that can generally be expected:
    - sawn wood 56-68%
    - plywood 50%
    - waferboard 75-80%
    - strandboard 85-90%
    - particle board 90-95%
    - thin particle board 100%
    - high density fibre board 95%
    - medium density fiber board 85-90%
- Plywood substitutes will result in better forest utilization.

Nik, A.R. & Harding, D. 1993 Effects of selective logging methods on water yield and streamflow parameters in Peninsular Malaysia. *Journal of Tropical Forest Science* 5(2): 130-154.
- Mean basal area in the watershed studied was 26.9 m^2/ha (held as a well stocked forest).
- Study of the effect of commercial (conventional) logging and planned/supervised logging on water flow in streams after logging.
- Commercial logging had a minimum cutting dbh for dipterocarps of 60 cm and 45 cm for non-dipterocarps, minimal road planning, 60 m/ha of logging road and 80 m/ha of skid trail, and no buffer strips specified.
- Planned/supervised logging had a minimum cutting dbh for dipterocarps of 90 cm and 60 cm for non-dipterocarps, good road planning with minimum coverage (<6%), grades (<20%), culverts and cross drains, 70 m/ha of logging road and 30 m/ha of skid trail, and 20 m buffer strips on each side of the stream.
- The stocking removed (assuming percent of basal area) in the commercial logging was 40% while in the supervised logging it was 33%.

- The commercial logged area resulted in 55% higher water yield than the supervised logged area, although the percent of forest removal was only 21% higher (i.e., 40% vs. 33%).
- Skid trail density was 60% higher in the commercial logged area, and the ground disturbance (skid trails, logging roads, landings) was limited to 5.1% in the supervised area as compared to 7.1% in the commercial area.
- Study demonstrated the positive effects of planned/supervised logging on hydrological responses.

Nikles, D.G. 1992 Successful domestication and conservation of an indigenous rainforest conifer (*Araucaria cunninghamii*) by means of plantations. *In*: *Beyond the guidelines - an action program for sustainable management of tropical forests. International Tropical Timber Organization, Technical Series No. 7*. P.163.
- Grows in PNG and NSW (Australia) to heights of >60 m and dbh >190 cm.
- 45,000 ha of plantations since 1920's.
- Rotation of 50 years or earlier (best trees at this time 40 m tall and 80 cm dbh with a merchantable volume of 8 m^3).
- MAI averages 12-18 m^3/ha/yr.

Noack, D. 1995 Making better use of tropical timber resources. *ITTO, Tropical Forest Update* 5(2): 12-13.
- After three years of study ranging across four tropical countries (Ghana, Cameroon, Indonesia (East Kalimantan) and Malaysia (Sarawak), it is possible to report that greater efficiency in forest and processing operations could greatly enhance the sustainability of the tropical timber industry.
- Report on ITTO project PD 74/90 (available from ITTO Secretariat).
- Of total tree on average 4.6% in stump, 5.2% in buttress, 53.5% extracted log, 10.4% stem offcuts, 26.3% crown diameter >20 cm.
- Of stem between crown and stump 77.4% extracted as log.
- Sawmilling yield (four countries compared):

	Yield of sawn timber, %			**Yield of wood residues, %**		
	Main product	**Total**	**By-product**	**Solid residues**	**Total**	**Sawdust**
Ghana (2 mills)	44	49	5	40-43	51	8-10
Cameroon (3 mills)		36			64	
Indonesia (2 mills)		50		36	50	14
Malaysia - swamp logs (local market) - dipterocarp (export market)		45 57		47	55 43	8

- There is a great influence of log quality on sawmill yield.
- Timber yield could be increased if mills used log rotation equipment at the first saw, which would enable the sawyer to cut each log optimally with regard to cracks and other defects.
- Also important is accuracy of sawing in order to avoid variations in board thickness that often exceeded 10 mm.
- Relatively small amounts of solid residues were used locally for joinery, furniture or charcoal production or as firewood.
- The situation was even worse for sawdust.
- Enormous potential for efficiency gains possible in logging and in mill processing.
- A thorough pre-logging inventory is an important step in efficient logging.
- Logging techniques need to be improved to reduce logging damage (needs regulations and encouragement for concessionaires, training of logging personnel and research into the most appropriate machinery).
- Need proper road planning.
- Government policy should aim to encourage the use of forest residues without compromising the sustainability of forest management.
- Different wood processing lines should be integrated to the largest extent possible (e.g., raw material sorting in a central log yard according to different wood processing lines (sawmilling, plywood, moulding products) may increase overall yield).
- Development of downstream products from wood residues.
- Urgent need to increase the level of technology (e.g., higher accuracy sawing, reduced saw kerf, log rotating equipment).
- In addition to modernization, need to raise the skill of the workers by practical training and education (i.e., machine operators at headrig, edgers and trimmers).
- Need establishment of quality control in the mills.
- Downstream activities such as furniture manufacturing, parquet flooring and profile board production should be encouraged.

- Conversion of wood into energy, especially to provide power for the wood processing industry itself, should be developed.

Nussbaum, R. & Hoe, A.L. 1996 Rehabilitation of degraded sites in logged-over forest using dipterocarps. *In*: A. Schulte and D. Schöne (eds.). *Dipterocarp Forest Ecosystems: Towards Sustainable Management*. World Scientific Publishing Co. Pte. Ltd., Singapore. p.446-463.

- The number of trees harvested per hectare in dipterocarp forests varies but rarely exceeds 10-12 trees/ha.
- In Sabah the cost of rehabilitating 7 ha of log landings with mixed indigenous species with a 2 x 1 m spacing was 1100 USD/ha (includes cost of planting stock, transport, site preparation, planting and fertilizing).

Nwoboshi, L.C. 1987 Regeneration success of natural management, enrichment planting, and plantations of native species in West Africa. *In*: Mergen, F. and J.R. Vincent (eds.). *Natural Management of Tropical Moist Forests - Silvicultural and Management Prospects of Sustained Utilization*. Yale University, School of Forestry and Environmental Studies, New Haven, Connecticut. p.71-91.

- The limited forest land base in West Africa.
- Enormous pressure for its conversion to other uses.
- Failure of natural regeneration systems and continuously increasing demand for wood make the plantation system the most logical choice for the region.

Odoom, F. 2002 *Impacts of Forest harvesting in Ghana. Case Study Report*. Food and Agriculture Organization of the United Nations, Rome, Draft Report, 48pp.

- This study was part of the case study series on forest harvesting practices in four ACP African countries to field-test the draft harvesting code.
- The countries involved include Ghana, Central African Republic, Congo and Gabon. The criteria for the selection of the local timber companies were that their technique and scale of operation must be representative of the country, the company must be working systematically and there must be data on the forest block being worked on.
- The study was carried out around the Tano-Suhien Forest reserve, which is located in the Sefwi Wiaso District of the Western Region of Ghana.
- The study focussed on the harvesting efficiency and the environmental and social impact of timber harvesting in the area.
- For the Harvesting efficiency - time and production studies were undertaken along with an appraisal of the equipment and personnel.
- For the environmental impacts - an assessment was made of skid trails and the damage to the residual stand as well as the extent of the canopy openings resulting.
- Forest-fringe communities were assessed to determine the sociological impacts of the forest operations.
- Mean volume extracted per cycle: felling = 13.04; skidding = 10.02.
- 86 trees < 50 dbh were totally destroyed whilst 48 were partially damaged.
- In the > 50 cm dbh size class 5 trees were partially damaged.

Ohman, **K. & Lamas, T.** 2003 Clustering of harvest activities in multi-objective long-term forest planning. *Forest Ecology and Management* 176: 161 – 171.

- Models used in long-term forest planning were generally, until recently, non-spatial.
- The locations of harvest activities were considered first in lower, more short-term steps of the planning hierarchy. However, now that issues related to biodiversity, recreation and road planning have to be considered, this is no longer a viable option.
- The spatial arrangement of harvest activities affects parameters such as the proportion of undisturbed interior forest and the sites of new roads. Thus, in long-term planning the spatial location of harvesting operations needs to be taken into consideration.
- However, including spatiality in long-term planning complicates the planning problems, and requires the development of new methods and approaches.
- This study presents a new approach for clustering harvest activities in time and space in long term forest planning. The planning problem essentially consists of maximising the weighted sum of the net present value of future forest management and the clustered volume of timber to be harvested.
- This objective is subject to the restriction that a certain volume should be harvested each period. Since the spatial dimension leads to a problem that is difficult to solve with ordinary optimization techniques, the ensuing problem is solved with a heuristic technique called simulated annealing.
- In a case study the suggested approach is applied to a landscape consisting of 2600 stands in southern Sweden.

- The results indicate that the model is effective for clustering the harvest and that it is possible to aggregate the harvest with only a small sacrifice of the net present value.

Ola-Adams, B.A. 1987 Effects of logging on the residual stands of a lowland rainforest at Omo Forest Reserve, Nigeria. *Malaysian Forester* 50: 403-413.
- Study based on a single 1 ha plot subjectively located in a 5 month old logged compartment.
- Manual logging where logs lifted directly onto lorries which gained access along hand-cut access routes.
- Basal area in undisturbed forest generally 29 m^2/ha; disturbed forest 14.3 m^2/ha; and secondary regrowth 11.7 m^2/ha.
- Logging intensity was 9 m^3/ha.
- In the 1 ha plot there were 3 stumps, 670 trees (girth dbh >10 cm) left.
- 17.7% of the residual trees were damaged.
- 51 trees were knocked over (mostly in the >30 cm girth class).
- 8% of area bared, compared to 30% for mechanized operations.

Ong, R.C., Logan, P.M., Glauner, R., Kleine, M. & Uebelhör, K. 1996 Examples of sustainability criteria for dipterocarp forest management. *In*: A. Schulte and D. Schöne (eds.). *Dipterocarp Forest Ecosystems: Towards Sustainable Management*. World Scientific Publishing Co. Pte. Ltd., Singapore. p.274-292.
- It was found that numerous indicators and their corresponding specifications already exist, however, may are difficult to assess.
- Also it is impractical to scrutinize a large number of specifications each time an evaluation or inspection for enforcement purposes is done.
- From the entire range of indicators the most appropriate ones were selected, e.g., for forest harvesting as presented in the following table.
- Criteria for sustainable timber harvesting operations:

Criteria	Indicator	Specifications	Mitigating measure
The timber stand is able to recover by	size-class harvested	- trees >60 cm dbh and <120 cm dbh	- tree marking
means of natural regeneration	trees retained (n/ha)	- protected species (e.g., fruit trees) - 5 trees/ha; dbh>60 cm as seed source if regeneration in insufficient - potential crop trees (10-40 cm dbh)	- tree marking
Impact of felling operation limited	felling damage	<20% of the residual stem number	- directional felling - no felling on slopes >25º
Impact of yarding operation limited	area of bare soil exposure	<15% of harvesting area	- tractor skidding only on slopes <15º - skyline systems on steeper slopes
	yarding damage[1]	<15% of the residual stem number	- felling in herring bone pattern - bucking logs to length <= 8 m

[1]Damage is define as an unrecoverable injury to a tree, so that it might die or be at least permanently devalued in its ecological or economic function

Palmer, J. & Synnott, T.J. 1992 The management of natural forests. *In*: Sharma, N.P. (ed.). *Managing the World's Forests*. Kendall/Hunt Publishing Co., Dubuque, Iowa. p.337-373.
- One of the many paradoxes of tropical forestry over the past 30 years is that the rise in public interest has been paralleled by a decline in the application of systematic management.
- Another paradox is that the same period has seen a great increase in research on tropical biology but little corresponding incorporation of research results into management practice.
- The main reason forest management has failed in the past century in the tropics has been the lack of any guarantee that forest would remain as forest. The absence of security and tenure discouraged forest managers from investing time and money in management for future production and often led to such investments being lost.

- For example, in Queensland, the system that had belatedly become the best managed and documented and most researched in the world for management of tropical moist forest was closed down by a political decision resulting from a state-federal struggle for supremacy and from a failure of communication between foresters and conservationists.
- While the merits of various forest management systems are being debated, tropical silviculturalists are of one voice in advocating the use of reduced impact logging techniques.
- The control of harvesting operations is the most important condition for sustainable management after the long-term security of the forest itself.
- Re-entry - the return of loggers to take previously non-commercial species or sizes, which was demonstrated to be highly damaging to regeneration more than 35 years ago - is still a problem in many countries.

Panfil, S.N. & Gullison, R.E. 1998 Short term impacts of experimental timber harvest intensity on forest structure and composition in the Chimanes Forest, Bolivia. *Forest Ecology and Management* 102 (2-3): 235-243.

- The harvesting intensity ranged from 1-6 trees/ha.
- The area of vegetation damaged by logging was a quadratic increasing function of the harvest intensity.
- Both harvest mortality and total mortality (trees harvested plus damage to the residual stand) were quadratic increasing functions of harvest intensity when expressed in terms of basal area.
- The median distance to the nearest gap decreased from 24.9 m at a harvesting intensity of 1 tree/ha to 8.3m at 6 trees/ha.
- The level of damage to the residual basal area was very low because mortality was concentrated on trees in the smaller size classes.
- Of three commercial tree species surveyed, only the seedlings and saplings of *Hura crepitans* showed a significant positive relationship between relative growth rate and harvesting intensity.
- Tree species loss was relatively low and constant across a range of harvesting intensities.

Pariona, **W., Fredericksen, T.S., & Licona, J.C.** (*in press*) Natural regeneration and liberation of timber species in logging gaps in two Bolivian tropical forests. *Forest Ecology and Management*.

- One-year-old logging gaps were sampled in dry and humid selectively-logged Bolivian tropical forests to determine the density of commercial tee regeneration.
- The efficacy of liberation treatments designed to enhance the growth and survival of sapling regeneration was evaluated over a period of 2 years.
- Liberation treatments included manual cleaning of competing vegetation around commercial tree saplings occurring in logging gaps, or spraying competing vegetation near these saplings with one of two herbicides (2,4-D or glyphosate).
- Of the nine species harvested in each forest type, only two species in each type had relatively abundant regeneration in logging gaps (*Hura creptans* and *Schizolobium parahyba* in humid forest and *Centrolobium microchaete* and *Caesalpinia pluviosa*).
- After 1 year, liberation treatments significantly increased the diameter growth of saplings in the humid forest, but not during the second year (P=0.09). In the dry forest, liberation treatments did not affect the diameter of liberated plants.
- Liberation treatments did not significantly affect sapling survival or height growth in either forest. Treatment costs were relatively low US$1-2.3 per gap), but time until return on investment is long (20-30 year cutting cycles).
- Adjustments to liberation treatments, such as season and intensity of application may increase effectiveness of treatments.
- Problems observed in this study with the recruitment of commercial tree regeneration in logging gaps suggests the need for site preparation treatments and more judicious seed tree retention.

Parren, **Marc & Bongers, F.** 2001 Does climber cutting reduce felling damage in southern Cameroon? *Forest Ecology and Management* 141: 175 – 188.

- In the lowland rain forest in southern Cameroon, an experiment was set-up to test whether pre-felling climber cutting could reduce logging damage.
- The abundance of lianas in the forest and their resprounting capacity after cutting was assessed.
- Logging damage was considered as tree mortality and tree damage in the felling gaps and the sizes of the creates gaps after felling.
- Lianas were very abundant: on average nearly 5000 individuals (at breast height) of which over 100 large ones (≥5 cm DBH) per ha. 70% of monitored lianas had died 22 months after cutting. Resprouting capacity was high but variable among species.
- Felling gap sizes (average 550 m2 per felled tree), tree mortality (12 trees per felled tree) and damage (20 trees per felled tree) were not significantly affected by pre-felling climber cutting.

- A minority of the damage was severe. Smaller trees were most prone to destruction and severe damage.
- The results show that pre-felling climber cutting has no significant effect on resulting gap-sizes, tree mortality and damage levels.
- Climber cutting before a logging operation does not contribute to damage reductions at the felling sites in African moist forests where the logging intensity is extremely low.
- Climber cutting should be applied on a tree-by-tree basis only, and after a careful judgement of the tree's liana load.

Pearce, **D., Putz, F.E. & Vanclay, J.K.** 2003 Sustainable forestry in the tropics: panacea or folly? *Forest Ecology and Management* 172: 229 – 247.

- The profitability of uncontrolled logging can be a significant obstacle to sustainable forest management, especially in the tropics. Rice et al. [Scientific American 273 (1997) 34] have argued that not only does traditional selective logging provide higher returns but also incurs less damage to forests than sustainable forest management systems that involve harvesting of many species and the creation of large gaps in the forest canopy to foster regeneration of light-demanding species.
- They claimed that protected areas were the only viable way to conserve forest ecosystems and proposed that loggers be allowed to log forests selectively once, after which the forests should become parks.
- Here, a response to the challenge posed by Rice et al. is given by exhaustively reviewing the evidence regarding the viability and desirability of sustainable forest management in the tropics.
- Following Rice et al., the term conventional timber harvesting is used to refer to existing practice, which typically pays little attention to maintaining long-term timber supply. Sustainable timber management implies taking steps to ensure forests continue to produce in the longer-term, while maintaining the full complement of environmental services and non-timber products of the forest.
- Empirical studies tend to confirm the conclusion of (Rice et al. [Scientific American 273 (1997) 34] that although sustainable timber management sometimes provides reasonable rates of return, conventional timber harvesting is generally more profitable.
- This implies that without additional incentives, one cannot expect companies to adopt sustainable management. The short-sightedness of many loggers, the slow rise in international timber prices, political uncertainty, and tenure insecurity simply reinforce this tendency.
- However, the claim that sustainable timber management generally damages forests more than conventional logging is rejected. Rice et al. base their conclusion largely on the particular case of mahogany extraction from Bolivia, and even there it may not hold.
- In many cases, sustainable timber management performs better in terms of carbon storage and biodiversity conservation than conventional logging approaches, as well as producing more timber.

Pereira Jr., R; Zweede, J., Asner, G.P. & Keller, M. 2002 Forest canopy damage and recovery in reduced-impact and conventional selective logging in eastern Para, Brazil. *Forest Ecology and Management* 168: 77 – 89.

- Ground and canopy damage and recovery following conventional logging (CL) and reduced impact logging (RIL) of moist tropical forest in the eastern Amazon of Brazil. ▪ Paired conventional and RIL blocks were selectively logged in 1996 and 1998.
- Harvest intensity was approximately 23 m3/ha.
- Ground damage in the CL treatments occupied 8.9-11.2% of the total operational area as compared with 4.6-4.8% for RIL. ▪ Blocks logged in had integrated canopy gap fractions of 21.6 and 10.9% of total area for CL and RIL blocks respectively.▪ Blocks logged in 1996had 16.5 and 4.9% gap fraction for CL and RIL blocks respectively.

PG&E National Energy Group 2002 *Reduced Impact Logging: Sabah, Malaysia Case Study*. Case Study Report, PG & E National Energy Group, Malaysia.

- From 1992 through 1998, PG&E National Energy Group (NEG) conducted a series of projects to test and demonstrate the application of reduced impact logging as a method for producing verifiable and quantifiable carbon sequestration.
- NEG verified that RIL had been successfully implemented by the inspection reports of an Environmental Audit Committee.
- It is estimated that over the 40 years following harvest, the first RIL project will sequester 485,000 tons of carbon.

Pinard, M.A. & Cropper, W.P. 2000 Simulated effects of logging on carbon storage in dipterocarp forest. *Journal of Applied Ecology* 37(2): 267 – 283.

- A model was constructed to simulate changes in biomass and carbon pools following logging of primary dipterocarp forests in southeast Asia.
- A physiologically driven tree-based model of natural forest gap dynamics (FORMIX) to simulate forest recovery following logging.
- Following selective logging, simulated ecosystem carbon storage declined from prelogging levels (213 Mg C ha-1) to a low of 97 Mg C ha-1, 7 years after logging.
- Carbon storage in biomass approached prelogging levels about 120 years after logging.
- The relationship between fatal stand damage and ecosystem carbon storage was not linear, with biomass recovery following logging severely limited by 50-60% stand damage.
- Results suggest that when 20-50% of the stand is killed during logging, replacing persistent forest species with pioneer tree species can reduce the site's potential for carbon storage by 15-26% over 40-60 years.

Pinard, M.A., Putz, F.E., Tay, J. & Sullivan, T.E. 1995 Creating timber harvest guidelines for a reduced-impact logging project in Malaysia. *Journal of Forestry* 93(10): 41-45.

- Uncontrolled logging results in excessive damage to the residual forest and reduces the forest's value for future timber production (Ewel and Conde 1980).
- Sabah - 40% of the state area is designated as commercial forest reserve, and all trees of commercial species (about 150 species) with a dbh of 60 cm or greater can be felled.
- Reduced Impact Logging (RIL) to reduce damage to the residual stand and soil through good inventory and mapping, pre-planning, pre-cutting of vines, directional felling, good location of roads and skid trails, using the winch and skid pans/arches on crawlers, and other environmentally sound management techniques.
- Typically 8-10 trees/ha removed (60-150 m^3/ha/entry; however, most typically 80-100 m^3/ha extracted), and an associated 40-70% of the residual stand is damaged.
- Vine cutting reduces damage, reduces post felling vine infestations, and increases light to the forest floor before felling and thus smaller trees can adjust.
- Trees uprooted in conventional logging 37%, while where RIL guidelines implemented it was 13%.
- RIL areas skid trail coverage was 3.4% on average, where in adjacent conventional logged areas it was 12% on average.
- % of trails with soil exposed was 38% in RIL areas, while for conventional areas it was 87%.
- RIL results in at least 50% less logging damage to soil and residual trees.
- Felling rate slower in RIL due to marking and preparing trees for felling.
- Planning and mapping cost more in RIL and map preparation accounted to 18% of the cost of implementing the guidelines.
- RIL results in reduced bulldozer maintenance cost (less side cutting and blading, rough and rocky areas avoided, and less driving), lower bulldozer skidding time, no need for enrichment planting and logging cycle time can be reduced due to less damage to residuals.
- Need for good training of all people involved from fellers to technicians and foresters.
- Timber volumes extracted and logging damage in Sabah, Malaysia. Mean values (with SD) from four logging units of each logging method:

	Logging Method			
	Conventional		**Reduced-impact**	
	Mean	**SD**	**Mean**	**SD**
Logging intensity, trees/ha	13.6	2.7	8.8	3.6
Logging intensity, m^3/ha	152	23	103	54
Proportion of area with soil disturbance	0.17	0.02	0.07	0.03
Skid trail density, m/ha	199	36	67	26
Proportion of trees killed during logging (5-60 cm dbh)	0.41	0.11	0.15	0.07
Density of undamaged dipterocarp trees (5-20 cm dbh)	49	24	104	62

Pinard, M.A. & Putz, F.E. 1996 Retaining forest biomass by reducing logging damage. *Biotropica* 28(3): 278-295.

- In the study logging intensity was 154 m^3/ha (CL) and 104 m^3/ha (RIL).
- In Sabah on average 8-15 trees/ha are felled, which is 50-120 m^3/ha logging intensity.
- In conventional operations as much as 30-40% of the area is traversed by crawler tractors (Chai 1975, Jusoff 1991), and 40-70% of the residual trees are damaged (Fox 1968, Nicholson 1979).
- Typically, little pre-harvest planning is carried out and the activities of fellers and bulldozer operators are not well co-ordinated.

- No correlation was found between volume removed and damage to residuals.
- First cuts in Amazonia usually <50 m^3/ha (Uhl & Viera 1989, Thiollay 1992, Verissimo et al. 1992).
- First cuts in Africa usually <30 m^3/ha (Nwoboshi 1987, Ola-Adams 1987, Klo & Ekwebelam 1987, Wilkie et al . 1992, White 1994).
- In conventionally logged area 66% of residuals damaged, similar to other studies done in Sabah.
- RIL 27% of trees >10 cm dbh were damaged and 19% were dead within the first year after logging.
- CONV 54% of trees >10 cm dbh were damaged and 46% were dead within the first year after logging.
- Logging damage in RIL was 50% of that in CONV.
- RIL had less severely damaged trees than in CONV (15% vs. 41%).
- Contains a table outlining in detail the RIL operations of harvest planning, pre-felling vine cutting, skid trail planning, direction tree felling, skidding, landings, and closing operations.
- More and larger trees remained undamaged where RIL was practiced, hence future biomass increment and yields of marketable timber are expected to be greater in the RIL areas than in the conventional logging areas.

Pinard, M.A., Howlett, B. & Davidson, D. 1996 Site conditions limit pioneer tree recruitment after logging of dipterocarp forests in Sabah, Malaysia. *Biotropica* 28(1): 2-12.

- In Sabah 30-40% of the area is churned or scraped by bulldozers (Chai and Udarbe 1977).
- In heavily disturbed sites infestations of twining vines, grasses and sedges can be extensive (Forestal International Limited 1973).
- Trees >60 cm dbh logged and average volume removed 94 m^3/ha.
- One landing established for each 25-50 ha block.
- Seed availability does not appear to limit the establishment of pioneer trees in gaps, on landings, and on skid trails during the first year after logging. Instead, recruitment appears to be limited by unfavourable site conditions.
- Even in 15-year-old logged over forests of Ulu Segama, the traces of log landings and skid trails are visible as treeless patches and corridors.
- Improving harvesting practices to minimize the area covered by landings and skid trails will be more effective management than attempting to rehabilitate these areas following uncontrolled logging.
- The broadcasting of pioneer seeds in recently logged areas may be a reasonable management option for hastening tree cover in denuded areas, but only if it is combined with site preparations that improve conditions for the survival of pioneer tree species.

Pinard, M.A., Barker, M.G. & Tay, J. 2000 Soil disturbance and post-logging forest recovery on bulldozer paths in Sabah, Malaysia. *Forest Ecology and Management* 130: 213-225.

- The study was conducted in Eastern Malaysia.
- The conventional timber harvesting system is based on a minimum harvesting diameter of 60cm dbh.
- Prior to logging, forest structure and composition were similar in the conventional logging and the reduced impact logging areas, with mean basal area ranging from 25-33 m^2/ha.
- No difference could be found between the total volume of timber extracted per logging unit for both conventional logging and reduced impact logging.

- Timber volume extracted within the logging areas:

Logging area	Volume extracted (m^3/ha)	Ave. excluding unlogged sections (m^3/ha)	Skid trail width (m)
1976 Conventional logging	93-118	136	3.9
1988 Conventional logging	94		4.1
1991 Conventional logging	90-95		5.4
1993 Conventional logging	134-173		7.1
1993 Reduced impact logging	87-175	92	5.4

- In conventionally logged stands 59% of the residual trees <60cm dbh were damaged.
- In areas logged with RIL techniques 29% of the residual trees <60cm dbh were damaged.
- In conventional logging operations, 140m^2 of soil were disturbed per tree harvested.
- In reduced impact logging operations, 94m^2 of soil were disturbed per tree harvested.

- Soil disturbance in conventional and reduced impact logging units:

	Conventional logged units (% of total area)	Reduced impact logging units (% of total area)
Skid trails	4.7	3.3
Roads and Landings	11.9	3.5
Total area disturbed	16.6	6.8

- Types of soil disturbance recorded in conventional and reduced impact logging units:

	Conventional logging units	Reduced Impact Logging units
Area with sidecast soil (%)	2.1	0.4
Skid trail surface area (%)	9.9	3.2
Bladed	87.7	37.7
Churned	11.1	50.2
Compacted	1.6	12.1

- Skid trails with intact topsoil and litter layer were uncommon in conventional logged areas, but covered about 12% of the skid trails in RIL units. In these compacted areas, saplings and vines resprouted soon after logging.
- Soil disturbance was positively associated with harvested volumes in conventional logging areas, but not in reduced impact logging areas.
- The results of a time motion study conducted by Tay (1999) clearly indicated a greater efficiency of skidding in RIL units compared to conventionally logged areas. The skidding costs were US$ 1.98/m^3 for RIL techniques and US$ 4.51/m^3 for conventional techniques.
- The extent of soil disturbance found for conventional harvesting techniques in this study was at the low end of the range of published data for unsupervised logging in Malaysia, and was similar to values documented for Suriname and Australia.
- The proportion of skid trails with subsoil disturbance was less than half in RIL areas when compared to conventionally logged areas.
- Four years after logging, woody plant regeneration was better (more stems, greater species richness) in RIL than in conventionally logged areas. Churned skid trails in general showed a greater regeneration potential than bladed trails
- If disturbance of the soil is to be minimised, reducing the area traversed by bulldozers will be more important than reducing the traffic on any particular skid trail.

Pinard, M.A., Putz, F.E. & Tay, J. 2000 Lessons learned from the implementation of reduced impact logging in hilly terrain in Sabah, Malaysia. *International Forestry Review* 2(1): 33-39.

- The application of RIL techniques on 2,400 ha of old growth dipterocarp forest in south-eastern Sabah, Malaysia.
- The forests are diverse in tree species and heavily stocked with trees of commercial interest; the average basal area ranges from 25 to 33 m^2/ha (dbh> 10cm), about 68% of this is in commercial species.
- Conventional timber harvesting is based on a minimum harvesting diameter of 60cm dbh. The management system is a modified uniform system with a 60 year cutting cycle. Pre-harvest inventory and post-harvest regeneration inventory are usually carried out. Other silvicultural treatments such as climber cutting were dropped in the mid-1970s because high levels of damage associated with harvest meant that only a small portion of the residual forest warranted treatment.
- Timber volume extracted in RIL areas, when expressed per net area logged, were about 70 % of the area extracted with conventional techniques.
- Soil disturbance as a proportion of the total area in the study areas:

	Ulu Segama		Kalabakan		Gunung Rara
	RIL	CL	RIL	CL	RIL
Roads and landings (%)	3.3	4.7	0.4	n/a	1.2
Skidding trails (%)	3.5	11.9	9.1	8.0	6.9
Area w/disturbed soils (%)	6.8	16.6	9.5	10.2	9.3

[RIL = Reduced Impact Logging; CL = Conventional Logging]

- In general, the implementation of RIL reduced the soil disturbance substantially when compared to conventional harvesting techniques, both in terms of area damaged (from 13% to 9%) and degree of disturbance.
- The implementation of RIL guidelines was associated with additional direct operating costs of 135 $/ha or 1.27 $/$m^3$ (Tay 1999).

- An additional 45 $/ha was spent on monitoring. A less intensive monitoring program might be sufficient on an operational scale (Tay 1999).
- In RIL areas the number of trees in the diameter classes >60cm and 10-40 cm dbh was significantly higher than in conventional logging areas.
- Kleine (1997) suggests that the difference in stocking levels combined with the higher volume increment could translate into a reduction of the cutting cycle by 50%.
- Stand damage was generally within acceptable limits in RIL areas. The exception was where clusters of trees had been felled. This resulted in unacceptably large gaps.
- The damage to the residual stand could be reduced from 50% to 28% of the original stems by implementing RIL techniques.
- Skidding during wet weather periods resulted in deep tracks that could not be drained, increased soil compaction and subsoil disturbance.

Plonczak, M. 1989 Struktur und Entwicklungsdynamik eines Naturwaldes unter Konzessionsbewirtschaftung in den westlichen Llanos Venezuelas (Structure and development dynamics of a natural forest under concession management in the western llanos of Venezuela). *Gottinger Beitrage zur Land und Forstwirtschaft in den Tropen und Sobtropen*, No. 43. 139pp.
- Study in Venezuela.
- Logging intensity 14-24 trees/ha >40 cm dbh (average 18.3 trees/ha with 15.2 m^2/ha of basal area removed).
- Estimated rotation age of individual trees of 80-100 years, a 20 year logging cycle is proposed with the following limits: minimum felling dbh 40 cm; minimum of 30 merchantable trees/ha of dbh >30 cm left after the cut; a residual b.a. of 15 m^2/ha after the cut; maintaining b.a. maximum of 20 m^2/ha to promote increment; and removing a maximum of 7.5 m^2/ha or a cut of 36 m^3/ha at the end of the cutting cycle.
- 36 m^3/ha logging intensity on a 20-year cutting cycle (1.8 m^3/ha/year MAI) of merchantable species.

Plumptre, A.J. 1996 Changes following 60 years of selective timber harvesting in the Budongo Forest Reserve, Uganda. *Forest Ecology and Management* 89: 101-113.
- Measures of forest structure show that more than 50 years is required for the forest to recover to pre-logging levels.
- 428 km^2 (42800 ha) of forest area.
- The total volume of timber removed, mean volume per hectare and mean percentage of timber that was mahogany per compartment in Budongo Forest for each decade since 1930:

Decade	Total volume m^3	Logging intensity m^3/ha	Calculated area logged, ha	Percentage mahogany
1930-39	66 016	32.2	2 050	71.3
1940-49	170 080	42.9	3 965	68.3
1950-59	151 334	42.1	3 595	74.9
1960-69	247 110	25.1	9 845	65.8
1970-79	171 836	38.0	4 522	66.0
1980-89	66 251	24.9	2 661	61.9

- Volume harvested in 1940-50's peaked due to waiving of the felling limit.
- Total area over the 60 years 26 638 ha or 62% of forest.
- Those areas that had been logged and treated with arboricide did show a greater tree species richness per unit area than the unlogged and untreated areas (may be due to the succession towards monodominance that occurs in Budongo).

Poore, D & Sayer, J. 1987 *The Management of Tropical Moist Forest Lands: Ecological Guidelines. International Union for Conservation of Nature and Natural Resources*, Gland, Cambridge, U.K. 63pp.
- Previous guidelines produced in 1976.
- In the 10 year elapsed no easing of the rate at which tropical forests are degraded or transformed to other, often less sustainable uses. However, there has been a great increase in knowledge and understanding of tropical ecosystems.
- A well-managed tropical forest is a constantly self-renewing resource.
- The greatest problem restricting benefits from tropical moist forests is careless management for short-term profit.
- The greatest limitation to practicing sustained yield management of tropical forests are inappropriate government policies (which favour clearance followed by plantations) and the international timber markets (which favour the logging of a relatively few species in tropical forests).
- History has demonstrated that:

- forest benefits are of value at all stages of economic development
  - forestry provides a good fulcrum for rural development
  - a well-managed forest (that is not restricted to the intensive production of only a few products) can respond to changing demands
- It is also generally accepted that:
  - the direct financial costs of many environmental problems caused by deforestation (such as flooding and soil erosion) are high
  - the values of non-marketed ecological benefits, such as climate regulation and the protection of downstream agriculture, may also be significant
- In timber mining operations it is usually the logging companies which gain because stumpage fees are too low, governments do not discriminate between species, licenses are based on volumes removed and not merchantable timber in the tract, and leases to logging companies are far shorter than timber rotations. All these factors encourage the loggers to abuse the resource.
- Tropical soils are highly susceptible to degradation, particularly if they are physically disturbed or exposed to sun or the direct impact of heavy tropical rainfall.
- Plantations, agricultural lands, pastures and modified forests often make less efficient use of nutrients present in the forest, than natural ecosystems that have evolved there.
- Various forms of the selective management system are now considered appropriate for large areas of Asia and Africa. The degree to which they succeed depends upon the care with which they are applied and the frequency of desirable species in the original stand.
- The best specifications for management differ from one forest to another. In some areas there is already sufficient knowledge for good management. Elsewhere research is required, and until the information becomes available, it is best to exercise caution.
- Management of natural forests is preferred over plantations.
- Where options still exist countries should attempt to derive the maximum of their timber needs from a managed `natural forest estate'.

Pretzsch, J. 1997 Möglichkeiten und Grenzen der Bewirtschaftung von Tropenwald aus sozio-ökonomischer Sicht: Status quo und Perspektiven. *Forstarchiv* 68: 223-228.
- In general, it can not be assumed that timber production in tropical forests is feasible in a sustainable manner considering the ecological and socio-economic components of sustainable resource management.
- The implementation of low impact logging will increase the initial costs of harvesting operations and therefore reduce the land value and revenue at least on the short run.

Putz, **F., Dykstra D.P. & Heinrich, R.** 2000 Why poor logging practices persist in the tropics. *Conservation Biology* 14 (4): 951 – 956.
- Despite abundant evidence that both the environmental damage and the financial costs of logging can be reduced substantially by training workers, pre-planning skid trails, practicing directional felling, and carrying out a variety of other well-known forestry practices, destructive logging is still common in the tropics. The authors discuss seven possible reasons for this seemingly irrational behaviour.
- **RIL is too expensive**. RIL has been demonstrated to be less costly per unit volume of timber yarded to the roadside than conventional, unplanned logging. Two main reasons why this simple fact may be ignored are: (a) the primary financial beneficiaries of the expected RIL savings are not the same people who decide whether or not RIL methods are to be used. (b) The actual cost savings of RIL are less than those calculated from small scale research plots when derived under typical industrial logging conditions and at the scales at which most commercial loggers operate. There are several factors which will influence the logging operation which are not (necessarily) taken into account during a feasibility study. E.g. The implementation of RIL demands that forest workers be trained. Trained workers may then demand higher wages and benefits, there by reducing the overall profits to be gained from RIL.
- **There's nothing wrong with current logging practices** With high profits being derived from conventional logging, loggers will be hard pressed to voluntarily admit that there is something wrong with the current system of logging and adopt RIL techniques.
- **Lack of governmental incentives to change logging practices** In most tropical countries there is National legislation which should guard against poor logging practices. These are however, never adhered to or circumvented where possible. Governments may take steps to offer SFM based incentives to forest owners and/or loggers. However, if profits remain high, then it will be unlikely that these incentives will be influential.
- **The forest will be converted anyway** Forest clearing for agriculture remains one of the major causes of deforestation in the tropics. Loggers operating in areas destined for conversion, are unlikely to make an effort to protect regeneration and potential crop trees.

- **Available equipment is unsuitable for RIL** Most aspects of RIL do not require special equipment (e.g. pre-harvest planning) and can be executed successfully with the current standard equipment. However some aspects remain dependent on a change in the existing machinery to reduce damage to the residual stand.
- **Lack of training and guidance by RIL experts** More training programs are needed for forest workers and managers, but both groups need first to be motivated to improve their methods. The onus for providing RIL training must lie with both national and international individuals/organisations concerned with sustainable forest management practices.
- **Lack of focused pressure for better logging from environmental groups** Most environmental groups focus their efforts on appealing for a cessation of logging and the establishment of more conservation areas rather than the implementation of better logging practices.
- Well-managed forests can provide income as well as many of the forest resources and ecosystem services that society increasingly demands, but what us required is nothing less than a cultural change from timber mining to forest management.

Putz, F.E. 1985 Woody vines and forest management in Malaysia. *Commonwealth Forestry Review* 64(4): 359-365.

- in lowland dipterocarp forests in Malaysia, wood vines increase damage associated with felling and slow rates of regeneration after selective logging.
- vine cutting before felling should be done sufficiently in advance so that the vines die and decay.
- this will reduce felling damage and prevent vine sprouting after the logging operations.

Putz, F.E. 1994 Approaches to sustainable forest management. *CIFOR, Bogor, Working Paper* No. 4. 7pp.

- Claims of sustainability are virtually impossible to prove but enough is known about tropical forest ecology and silviculture to protect ecosystem functions and maintain biodiversity while still deriving financial profit from logging.
- Lack of good management plans generally results in logging practices that destroy natural regeneration and increase forest susceptibility to soil loss, wildfires and weed infestations.
- To the apparent surprise of some loggers the environmental benefits resulting from the implementation of RIL are generally not expensive; harvest planning often reduces the cost of transport logs from the forest to the log pond, mill or port.
- There are also long-term benefits to the forest owner as less severely damaged forest recovers more quickly after harvesting.
- In dipterocarp forests in Sabah there is evidence that the directional felling ability of a trained over untrained chain saw operator may be as great as 100 degrees.
- Where control is not exercised over bulldozer skidding 30-40% of the area can be directly impacted in the removal of 10-12 trees/ha.
- Avoidance of damage should be the primary objective of management.
- The requirement of verifiable data on annual volume increments remains one of the main stumbling blocks to be faced by forest managers who want their operations eco-certified.
- The alternative to real and readily available growth and yield data in Southeast Asia is the questionable assumption that trees in logged but not silviculturally treated dipterocarp forests have a MAI of 1.0 cm/year and that these unmanaged forests accumulate timber at an annual rate of 1.0 m^3/ha/year. With proper management, these increments and perhaps better are achievable. The problem is that based on these assumptions in lieu of data, cutting rates that far exceed sustainable levels are seemingly justified.
- Once good forest management guidelines are developed and accepted, the next challenge is assessment of compliance.

Putz, F.E. & Viana, V. 1996 Biological challenges for certification of tropical timber. *Biotropica* 38(3): 323-330.

- Commercially-exploited forests are important components of local, regional, and global conservation and development strategies.
- Forest management can be more financially profitable, socially beneficial, and environmentally acceptable than competing land uses.
- Conversion of natural forest into pastures, plantations, and other non-forest land uses is less likely where the forest has commercial potential.
- By reducing the demand for and thus the financial value of forest products, boycotts may increase the likelihood of forest destruction.
- If conservation-minded consumers are willing to accept "organically certified" exotic vegetables grown in fields that formerly were forests or savannahs, it would be unreasonable for them to expect managed forests to be identical to protected areas in composition and structure.

- Conservation biologists interested in contributing to the forest certification process, however, may have to reconcile their preservationist principles with the unavoidable impacts of forest management. Whereas there is no inherent conflict between strict preservation and management, saving every species everywhere is not an option and neither is maintaining "pre-intervention" forest structure in forests managed for timber.

Quirós, D., Campos, J.J., Carrera, F., Castaneda F. & aus der Beek, R. 1997 CATIE's experiences in the development of log impact forest harvesting systems in Central America. *In*: *Proceedings of the FAO/IUFRO Satellite Meeting held in conjunction with the IUFRO XX World Congress*, Tampere, Finland, 4-5 August, 1995, Research on Environmentally Sound Forest Practices to Sustain Tropical Forests. Food and Agriculture Organization of the United Nations. p.15-26.
- Generally 400 trees/ha with dbh >10 cm, and 40 of these have a dbh >50 cm.
- Of the 40 trees with dbh >50 cm, 2-10 commercial trees/ha are removed in a typical cut.
- There can be between 100-150 tree species/ha.
- With increased wood scarcities in some parts non-traditional species are being increasingly logged.
- Trees sold in many cases at a very low price, just to get access to the forest so it can be converted to other uses.
- Also, a problem due to government paperwork and polices, which results in a lot of illegal logging.
- Lack of planning and control in logging operations in Central America.
- In Costa Rica 36 different species are considered commercial (only 4.3% of the land area is still forested).
- At the extreme Guatemala has vast forests and only two species are extracted in logging.
- Lack of integration between logging and the timber using industry, thus the industry has little incentive to control how the logging is done (although it should because it will affect their long-term well-being).
- The loggers only pay based on the volume removed, therefore they only take out the best and largest logs. This results in over 20% of the cut volume being unextracted.
- CATIE is basically another RIL system (good map with tree locations is a basis).
- Cost of the detailed inventory is $27.00/ha.
- Volume of unextracted wood, due to felling damage or poor quality, can be from 20-25% of the extracted volume. This type of material is suitable for supplying local market through small-scale sawmilling.

Rapera, R.B. 1978 Effects of logging on residual stands. *BIOTROP Special Publication* 3: 119-125.
- the success of selective silvicultural systems depends very much on the quantity and quality of the future crop trees left after logging
- The logger makes or unmakes the next harvest in the same area.
- Width of logging roads varies from 5-10 m, with the right of way extending from the road centre-line up to 15 m on both sides of main roads, and 10 m for spur roads.
- In highlead settings, damage to residuals due to felling was 23-28% and yarding damage 4-6%.
- In tractor skidding felling damage to residuals was 9% and skidding damage 2%.
- The higher felling damage in the highlead setting is probably due to working on steep terrain (>40% slopes), where felled trees tend to roll more and thus cause more damage to residuals.
- The growth rate of residual trees has been reported to be approximately 3.21 m^3/ha/year.
- Growth rates from various research results range from 1.60 m^3/ha/year to 8.55 m^3/ha/year.

Reid, J.W. and Rice, R.E. 1997 Assessing natural forest management as a tool for tropical forest conservation. *Ambio* 26(6): 382-386.
- Investments in "natural forest management" [NFM] are financially unattractive and governments are generally unwilling or unable to force loggers to make such investments.
- Most NFM initiatives can be categorised as polycyclic felling systems. The cutting cycle is 25-40 years.
- In the case of primary forest, there is generally an initial conversion phase in which the large volume of mature timber is harvested. In the subsequent phase a constant, smaller amount of wood is cut at regular intervals.
- Under conventional logging practices, little attention is paid to the condition of the residual stand. This harvesting practice is unsustainable, because the forest will not yield another harvest of the target species for a long time, if ever.
- RIL is not necessarily an improvement compared to conventional harvesting techniques. Where the topography is flat and commercial trees occur at very low densities (sometimes less than 1 tree/ha is extracted); conventional logging techniques may not cause avoidable damages.

Reitbergen, S. & Poore D. 1995 Forestry and the increased use of lesser used species. *ITTO, Tropical Forestry Update* 5(2): 6-7.

- In management systems based on selective felling, there are limits to harvesting intensity above which felling and skidding damage will be so high as to jeopardise the forest's regenerative capacity, no matter how well-planned and executed the operation.
- The figure of 10 trees/ha has been quoted as an order of magnitude for such an upper limit, and it is probably true that harvesting more than 10 trees/ha without seriously endangering a stand's future potential demands planning and operational skills beyond the current capacity of most concessionaires in the tropics.
- It is impossible to set universal threshold values for logging intensity: 1) damage to the remaining stand depends much more on management variables such as skid trail planning and machine operator skills than on the number trees harvested; and 2) acceptable damage limits vary according to the physical and biological characteristics of the forest site under consideration and the management objectives that have been set for it.
- In many forests in South America, e.g., the quantities of valuable timber species capable of responding to fairly heavy canopy opening appears to be restricted, whereas in Southeast Asia and Africa heavier canopy opening is almost always desirable.
- Increased harvesting of lesser used species seems to be a two-edged sword: it may have a positive or a negative impact on benefits derived from any given tropical moist forest, depending on the site characteristics, the management objectives chosen and the standard of forest management.

Reyes, M.R. 1978 Possibilities of increasing yields of tropical rainforest in the Philippines. *The Malaysian Forester* 41(2): 167-170.

- General logging performance up to the present results in secondary growth that is below the optimum potential of the forest.
- To have more young trees left uninjured after logging requires the training of fellers in felling techniques and yarding crews in yarding and skidding techniques, all with the objective of minimizing destruction and injury to young trees.
- Growth plots in residual stands in Eastern Mindanao show a total volume of 90 m^3/ha just after logging, whose predicted volume 30 years after logging is about 260 m^3/ha of which the harvestable volume of trees reaching 60 cm dbh and over is 160 m^3/ha (2.33 m^3/ha/year).
- With a 20% increase in residual stand the harvestable volume is increased to 190 m^3/ha (3.33 m^3/ha/year).
- A simulation projection of a treated (stand improvement through cleaning, thinning and release), second growth, logged-over dipterocarp forest in Eastern Mindanao shows a yield of 260 m^3/ha, 30 years after logging, compared with a yield of 176 m^3/ha in an untreated selectively logged area (increase of 44%). On a 40-year cycle the treated stand is projected to yield 375 m^3/ha compared to 182 m^3/ha in the untreated stand (increase of 89%).

Reyes, M.R. 1983 The selective logging system and its viability. *The Philippine Lumberman* 29(1): 20-30.

- Selective logging has been shown to be simple, logical and financially feasible by a few conservation-minded concessionaires.
- However, it has been a hard sell, perhaps because: excessive economic motivation; prejudice; vestiges of colonial mentality; dominance of concessionaires; lack of guts, dedication and sustained forestry leadership in an adverse society and political environment; and moral decadence.
- Found in field studies in 1950's that 58% or more of the young trees could be saved by the loggers using their ingenuity to avoid hitting marked young trees.
- Paper presents a stem distribution chart showing stocking levels by diameter class to ensure successful regeneration of dipterocarp forests using selective logging.
- Average growth rate used in calculations is 3 m^3/ha/year and the cutting cycle is 35 years.
- There are a few licensees who have fairly good residual forests.
- We find more of the inadequately stocked logged-over areas due to allowing logging as the loggers please.
- Empirical evidence shows that the old growth sawtimber cut may vary from 60 to 180 m^3/ha, but based on the prescriptions for the new selective logging system the yields may only be 30 to 90 m^3/ha.
- It has been shown that permissible cuts at the end of the cutting cycle of three study areas were almost equal if not greater than the average cut from the old growth (when selective logging was done properly).
- In one company where recently supervised logging was conducted, about 70% healthy residuals were achieved.
- There is a noticeable shift in attitude from predominantly exploitative-oriented to conservation-oriented logging.

Richter, F. 2001 Financial and economic assessment of timber harvesting operations in Sarawak, Malaysia. *Forest harvesting Case Study 17*. Food and Agricultural Organization, Rome.

- The Cost-Benefit-Analysis (CBA) reported here compares the project worth of two timber harvesting systems: (1) Conventional Logging (CL) and (2) Reduced-Impact Logging (RIL). Two time frames are included in the analysis: (1) One-year calculation period—the financial costs and revenues of CL and RIL are calculated for the year of harvest in a primary forest; (2) 40-year calculation period—the financial and economic project value is analysed until year 40 after logging, which includes timber production from a second harvesting operation.
- Data on cost, productivity, and damage to the residual stand as well as data on soil compaction were obtained from RIL and CL trial blocks in the FOMISS-Samling Pilot Area (FSPA). In addition, timber wastes due to poor utilisation and lost logs are estimated based on data collected in the FSPA. Figures on forest growth are predicted with the Dipterocarp Forest Growth Simulation Model (DIPSIM).
- The discount rate used in the analysis was set at 10%. For the calculation of shadow prices, a standard conversion factor of 1.2 on traded financial prices was applied.
- The financial analysis was carried out for two hypothetical blocks with a net production area (NPA) of 100 ha each. The net operable area (NOA) amounts to 90 ha under CL and 70 ha under RIL. As a consequence of soil compaction due to skidtrail and log landing construction the NOA for the second harvesting operation under CL is reduced by 13 ha, resulting in a NOA of 77 ha. Under RIL the NOA is reduced by 3 ha, resulting in a NOA of 67 ha.
- The results of the damage assessment demonstrated that the percentage of severely damaged trees was reduced from 54% under CL to 28% under RIL. This damage reduction leads to an increased quality of the future harvestable stand. Considering this point, a Quality Factor (QF) was introduced. Under CL a QF of 50% was defined; hence 50% of the volume increment consists of defective or damaged trees. A QF of 65% was set for the RIL management option.
- Timber wasted as a result of poor felling and trimming techniques was taken into account by defining an Utilisation Factor (UF). Under RIL a UF of 80% was calculated and for the CL a UF of 75% was estimated. Under CL the volume of timber wasted due to logs left on the log landing or due to second trimmings amounts to 20% of the total extracted volume, whereas in a planned harvesting operation the log wastage approaches 0%.
- The overall harvesting volume of the first harvest under CL averaged 44.5 m^3/ha and in the RIL blocks the harvesting volume averaged 27.8 m^3/ha.
- The potential harvesting volume in the second harvesting operation 40 years after the initial harvest would be 23 m^3/ha in CL and 83 m^3/ha in RIL. However, the maximum harvesting intensity under RIL was set at 40 m^3/ha/y.
- The financial analysis considers all costs associated with harvesting operations, including the cost of training, planning, skidtrail preparation, tree felling, log extraction and post-harvesting operations. The analysis also considers royalty payments and revenues from timber sales. Total harvesting costs under CL and RIL amounted to RM 28/m^3 and to RM 43/m^3 respectively (RM = Malaysian Ringgit). The average royalty costs, weighted according to the species harvested, were RM 37/m^3. For the calculation of timber revenues an export quota of 40% was considered. Under the RIL system a 10% certification premium was added to the prices. In order to calculate the profit from timber harvesting, the forest operation costs, which do not include costs for harvesting operations and royalties, were subtracted from the log price.
- The economic analysis takes into account the costs of the harvesting operation and the benefits from timber sales, carbon stocks, Non-Timber Forest Products (NTFP), soil values, recreational values, and biodiversity values.
- The economic value of timber revenues averaged RM 351/m^3 for CL and RM 387/m^3 for RIL (including a 10% certification premium). A total NTFP value of RM 6,798 per block (100 ha) and year was calculated for CL and a value of RM 9,764 for RIL. The annuity per block with regard to soil erosion benefits was estimated to be RM 1,442 (year 1-10) and RM 9,034 (> year 10) under CL and RM 4,526 (year 1-5) and RM 10,126 (> year 5) under RIL. In addition the following annual recreational benefits per block were obtained: RM 189.5 for CL and RM 1,895 for RIL. The annual economic value of biodiversity per block amounts to RM 625 for CL and to RM 898 for RIL.
- The profit was estimated at RM 29 and RM 45 per m^3 under the CL system and the RIL system respectively. However, considering the extracted volume, 4,005 m^3/100 ha NPA under CL vs. 1,942 m^3/100 ha NPA under RIL, the CL system is more profitable. The total profit per 100 ha NPA amounts to RM 117,566 under CL and to RM 88,318 under the RIL system.
- The high extraction volume in the first harvesting operation under CL strongly influences the results of the CBA with regard to the 40-year calculation period. The results show that both harvesting systems are economically viable at the applied discount rate of 10%. Disregarding the negative environmental and social costs connected with CL, this system is more profitable than the RIL system. This is also due to the effect of discounting over a 40 year period which reduces the higher commercial RIL volume and revenues of the second cut to a minimal amount. Considering the above, it becomes apparent why

the Net Present Value of the CL system is financially more profitable than the RIL system (NPV: CL = 118,700; RIL = 91,409).
- In contrast, the economic analysis demonstrated that from the society's point of view the

Romero, Claudia 1999 Reduced impact logging effects on commercial non-vascular pendant epiphyte biomass in a tropical montane forest in Costa Rica. *Forest Ecology and Management* 118: 117 – 125.
- Compatibility of different commercial uses of a montane tropical oak-bamboo forest in Costa Rica was assessed for selective logging and harvesting of non-vascular pendant epiphytes.
- Nine years after selective logging no negative impacts were detected on the biomass of these epiphytes at 1-3m range (the heights at which they are harvested).

Ruslim, Y. 1992 *Tropenwalderschliessung in Indonesien, am Beispiel der Forstkonzession PT.ITCI in Ostkalimantan*. Master of Science-Thesis. University of Göttingen. 1992. 85pp.
- The cutting cycle for the Indonesian Selection Cutting System is 35 years with a minimum residual density of potential crop trees of 25 trees/ha.
- The area affected by skidding ranged from 11.1% to 13.4% of the total area.
- The initial basal area was 33.19m^2/ha. The residual basal area was 14.5m^2/ha (44% of initial basal area) of undamaged and 8.58m^2/ha of damaged trees.
- For a second site the initial basal area was determined as 103.63m^2/ha, with a harvesting intensity of 39.1m^2/ha (approximately 33% of the basal area). 19% of the residual stand were damaged during felling and skidding operations. 44% of the initial stand remained undamaged after harvesting.

Ruslim, Y. 1994 *Der Beitrag eines planmässigen Erschliessungs- und Nutzungskonzeptes zur pfleglichen Holzernte im tropischen Regenwald, untersucht am Beispiel eines Dipterocarpaceenwaldes in Ostkalimantan, Indonesien*. Dissertation. Universitaet Goettingen. 1994. 139 pp.
- This study was carried out in eastern Kalimantan, Indonesia.
- The cutting cycle for the TPTI system (selection system with supplementary planting is set to 35 years. 20 trees of merchantable size (dbh _50cm) per hectare must be retained.
- On average 13.5% of the area were affected by skidding (on 8.7% of the area the topsoil was exposed).

- Damage to the residual stand by felling and skidding:

	Moderate slope		**Steep slope**	
	Basal area		**Basal area**	
	(m^2/ha)	**(m^2/ha)**	**%**	**(m^2/ha)**
Basal area prior to harvesting	22.03	100	25.43	100
Harvest	7.11	32.27	7.02	27.60
Felling damage to crowns	1.59	7.22	2.69	10.58
Felling damage to stems	3.79	17.20	2.63	10.34
Skidding damage	0.93	4.22	2.20	8.65
Sum of damaged trees	6.31	28.64	7.60	29.88
Basal area of undamaged trees in the residual stand	8.61	39.08	10.81	42.51

- With both ground conditions (moderate and steep slopes) felling and skidding damage amounted to 30% of the initial basal area.
- On most sites between 20 and 40% of the potential crop trees were damaged during harvesting operations.
- Between 6.9% and 9% of the area were affected by equipment movement.
- On moderate slopes an average of 189 m/ha of skid trail were constructed with unplanned logging compared to 260 m/ha in planned operations.
- On steep slopes an average of 216 m/ha of skid trail were constructed with unplanned harvesting compared to 280 m/ha in planned operations.
- Winching of logs to the skid trail was not possible due to the large volumes harvested per stem.
- Severe soil damage can be reduced significantly by implementing reduced impact logging techniques.

Ruslim, Y., Hinrichs, A. Sulistioadi, B. & Limbang Ganacea, P.T. 2000 *Study on implementation of reduced impact logging. SFMP Docoment No. 01a.*Ministry of Forestry and Estate Crops in Cooperation with Deutsche Gesellschaft für Technische Zusammenarbeit.
- This study was undertaken in the district of east Kalimantan, Indonesia at the location of salvage felling operations in virgin forest that had been burned slightly.

- The purpose of this study was to compare the effects of reduced impact logging [RIL] and conventional logging [CL].
- In general the stand condition was quite good even though it had been burned during the 1997/1998 fires. The potential for timber harvest was still high.
- The results of stand inventories indicated that 15-20 trees of commercial species could be harvested with an estimated volume of 70-90 m^3/ha.
- During the study the amount of trees felled was limited to 12 trees/ha with a volume of approximately 75 m^3/ha. It was felt that this was representative of heavy logging intensity.
- The study results would also be applicable in unburned forest, because the condition of the study area was that of an almost pristine forest.
- For felling activities there was no significant difference in work time and productivity. However, the work time per element (e.g. preparation for felling, bucking) was quite different.
- By implementing RIL procedures productivity in pure skidding was reduced by 34% (winching to a maximum of 30m, two helpers available) or 29% (winching to a maximum of 15m, one helper available) respectively.
- Due to the fact that a lot of time is usually lost due to machinery problems, bad weather and breaks, the overall reduction in skidding productivity per day was approximately 15% compared to CL operations.
- In the RIL units, harvesting caused less opening up of the canopy by a factor of 22% (winching maximal 15m) to 29% (winching maximal 30m).
- Level of opening up average/ha resulting from felling and skidding:

Parameter	**RIL**	**RIL (winching max. 15m)**	**CL**
Skid trails (m^2/ha)	554	726	1632
Percentage	5.5	7.3	16.3
Falling Trunks (m^2/ha)	139	139	137
Percentage	1.4	1.4	1.4
Falling canopy (m^2/ha)	1180	1180	860
Percentage	11.8	11.8	8.6
Opening up (m^2/ha)	1873	2045	2629
Percentage	18.7	20.4	26.3

- The impact of harvesting was high as after felling less than half of the residual stand >20cm dbh remained undamaged. The damage to the residual stand caused by felling was not significantly different between the two harvesting systems.
- The percentage of healthy trees in the residual stand could be increased from 35 to 47% by implementing RIL techniques (reduction by 28%).
- The chainsaw operators for both harvesting techniques were training in reducing waste. Nevertheless the exploitation factor in the RIL plots was greater (85%) than in the CL plots (81%). Using CL techniques most of the timber losses were due to logs left at the felling site as well as inefficient bucking.
- Timber utilisation in RIL operations was still less than optimal (stumps were cut too high, lengths above the first branch were not utilised).
- The operational costs for the tractor were reduced by 5% per months by implementing RIL (due to a reduction in work time for the tractor working with a heavy load).
- Comparison of forest harvesting operational costs using RIL and CL procedures (estimation of harvesting intensity = 48 m^3/ha):

	Conventional Logging (US$/$m^3$)	Reduced Impact Logging (US$/$m^3$)
1. **Planning Section**		
Pre-harvest stand inventory [ITSP]	0.09	-
ITSP and topographic survey	-	0.05
Planning/ mapping of skid trails	0.01	0.01
Marking skid trails	-	0.08
Total (US$/$m^3$)	0.10	0.24
2. **Production and Equipment Section**		
Opening up skid trails and "closing up"	-	0.35
Felling	0.23	0.23
Conventional skidding	2.45	-
· RIL skidding	-	2.75
Total (US$/$m^3$)	2.68	3.33
Total (US$/$m^3$)	2.78	3.56

- Using RIL techniques results in an increase in operational planning costs by US$ 0.14/m^3 and an increase in the overall operational production costs of around US$ 0.14/m^3.
- Overall the RIL system was by US$ 1.00/m^3 more expensive than the conventional harvesting system.
- Condition of the residual stand:

	CL	RIL
1. **Stand condition after harvesting**		
Healthy trees, dbh 20-40cm	22 m^3/ha	25 m^3/ha
Healthy trees, dbh > 40cm	76 m^3/ha	100 m^3/ha
2. **Regeneration potential**		
Enrichment planting/ Rehabilitation	Necessary on skid trails and landings	Only necessary on landings

- It is expected that the second harvest in the RIL plots could be undertaken within a shorter time frame.
- In areas with a lighter harvesting intensity or with more difficult topographic conditions RIL proved to have a higher increase in work efficiency (for felling) than found in this study.
- Under CL it was common for the tractor operator to skid two logs at once. With RIL this was rarely done in order to minimise damages to the residual stand.
- The implementation of RIL caused a decrease in skidding productivity by 15% per month due to additional time required for winching and a reduction of combined loads.
- Under RIL it is estimated that the chainsaw operator will have sufficient time for cross cutting trees that have fallen across the skid trail and are difficult for the tractor operator to position for extraction. This would help to reduce opening up resulting from skidding.
- Implementation of RIL reduced the overall opening up by 29%, the greatest reduction occurred due to the smaller size of the skid trails (55% reduction).
- Directional felling is very difficult, especially for trees that have a natural lean and/or are very large (dbh >70cm). Generally a wedge is only used for directing the fall of smaller trees and to avoid breakage of the log when cross cutting. Therefore the damage level to the residual stand could not be reduced significantly by implementing RIL techniques.
- Frequently logs bucked by the chainsaw operator where still trimmed further at the log landing or at the log yard. Therefore, to avoid that parts of the logs they deliver not being used, "waste" that is actually still utilisable was cut and left in the forest.
- The utilisation of timber above the first branch could be increased (often about 4-6m of utilisable timber were left behind).
- The increased operational costs associated with RIL were covered directly by the financial gains of increased timber utilisation. At the given harvesting intensity the timber production could be increased by 2 m^3/ha through better utilisation standards.
- Implementing the entire process of RIL under the conditions of this case study led to a direct financial benefit of US$ 50 per hectare, if the company had been allowed to harvest the "additional timber" under its given AAC.
- There are also long term benefits of an increase in quality of the residual stand, reduced need for rehabilitation and the possibility of shortening the cutting cycle.

Saenz, **Grace P. & Guariguata, M. R.** 2001 Demographic response of tree juveniles to reduced impact logging in a Costa Rican montane forest. *Forest Ecology and Management* 140: 75 – 84.

- The study was conducted in the Cordillera de Talamanca, Costa Rica, at the Villa Mills experimental site administered by CATIE.
- Jan 1991 – July 1992, controlled logging applied to 21 ha. Area divided into nine 1 ha plots, separated by 20-25 m wide buffer strips. Two logging treatments were randomly assigned to 4 replicate plots per treatment (total of 8 plots), plus a single control plot. The treatments consisted of extracting 20 (light) and 30% (moderate) of the stand basal area (stems ≥ 10 cm DBH).
- Height and diameter growth were assessed 5 years after logging along with individual survivorship of juveniles. Target species – *Quercus costaricensis*, *Q. copeyensis*, *Drymis granadensis*, *Ocotea austinii*, *Weinmania pinnata*. Two sample sizes used for seedlings (≥0.3, but < 1.5 m tall) and saplings (≥ 1.5 m tall but < 10 cm dbh).
- For seedlings, the overall 5-year mortality rate (exponential model) was significantly higher under the lightest harvest intensity while for saplings, no significant differences in mortality were detected among harvesting intensities.
- For all species combined, annual 5 year diameter and height growth rates did not differ significantly among harvesting intensities. Also for all species combined, annual 5-year diameter and height growth rates did not differ significantly among harvesting intensities for seedlings, although saplings grew significantly better under the higher harvest intensity.

- Results suggest that saplings of the study species were more responsive to overstory removal than seedlings.
- At the species level, *Quercus* showed the largest significant differences in growth rates across harvest intensities and also with respect to the other studied species in both size classes
- Costa Rican oak bamboo forests show promising silvicultural potential for timber management under low-impact logging prescriptions.

Sargent, C., Huszin, T., Kotey, N.A., Mayers, J., Prah, E., Richards, M. & Treue, T. 1994 Incentives for the sustainable management of the tropical high forest in Ghana. *Commonwealth Forestry Review* 73(3): 155-163.
- Incentives may be thought of as signals. They may be negative - disincentives - providing an alert or deterrent, or they may be positive, motivating and indicating action.
- Incentives are bad if they are unclear, contradictory, perverse or lead to market distortion.
- The majority of existing market and fiscal incentives (demand side incentives) encourage and promote extraction of high value species; while control (supply side) measures, including management plans, yield allocation and so forth, attempt to conserve high value species, promoting extraction of a wider range of lesser used species.· Field work and analysis fully supported the hypothesis that demand side incentives would be ineffective, and even deleterious, without attention to supply side issues.
- The sharing of management will be essential. Industry will need to accept a far greater responsibility for the resource if current predictions of the extinction rate of key economic species are to be averted.
- Good forest management requires technical knowledge of the resource.

Sarre, A. 2001 Extending the reach of RIL*. ITTO, Tropical Forest Update* 11(2) : 19.
- Rimbaka Forestry Operations has recently started introducing RIL to its operations.
- The Rimbaka Timber Harvester is an innovative machine developed by the company to reduce the density of skid trails during log extraction.
- Average length of skid trails in forest logged with the Rimaka Timber Harvester was less than 40 m/ha and the total area damaged was approximately 15%; well below the threshold set within the Malaysian Criteria and Indicators.

Sarre, A. 1995 Opening the door to lesser used species. *ITTO, Tropical Forest Update* 5(2): 1
- Increasing the use of lesser used species is seen by many as a way of making natural forest management more viable.
- First, by harvesting more volume per hectare, the same quantity of wood will be produced from less area, leading to the possibility that less forest area will be logged.
- Second, and more important, generating more revenue from a given area will increase the value of the forest and therefore its attractiveness as a long-term land-use option.
- Arguments that increasing logging intensity will cause more environmental impacts, and the economics of increasing the range of species used are yet to be proven.

Sarre, A. 1996 What foresters can do? *ITTO, Tropical Forest Update*, 6(3): 1
- The single most important thing that foresters can change is the way that forests are logged.
- There is no doubt that most current logging techniques cause unnecessary damage to the forest.
- Even without reducing volume cut, better logging techniques will have an immediate positive effect on the post-harvest value of the forest and will increase the long-term chances of sustainability.

Saulei, S. 1984 Natural regeneration following clear-fell logging operations in the Gogol valley, Papua New Guinea. *Ambio* 13(5-6): 351-354.
- Clearfelling was not as disastrous as may people predicted.
- Within a few months after felling bare ground was covered with natural regeneration, but new growth was less diverse.
- In the clear felled area soil phosphorous was 50% of that in closed forest (11.60 ppm vs. 22.00 ppm).
- Compacted tractor trails and landings, and denuded slopes and hilltops developed in many cases into grassland.

Sayer, J.A., Zuidema, P.A. & Rijks, M.H. 1995 Managing for biodiversity in humid tropical forests. *Commonwealth Forestry Review* 74(4): 282-287.
- Logging cycles 20-40 years with fewer trees removed rather than a very intensive cut every 70-80 years.
- Low intensity logging also protects sensitive understory species (plants, mammals, birds).
- 15.35% of all trees damaged in polycyclic harvesting, vs. 40-60% damaged in monocyclic systems (Bruijnzeel 1992).

- Low impact logging techniques are not difficult to implement and may be cheaper than conventional logging practices.

Sayer, J.A. & Byron, R.N. 1996 Technological advance and the conservation of resources. *Int. J. Sustain. Dev. World Ecol*. 3: 43-53.
- In recent decades, forest industries have placed a high premium on uniformity in the dimensions and physical properties of wood.
- New technologies for transporting and converting heavy hardwoods have radically changed the situation - plywood mills in the Amazon have already captured a major share of an international market where South-east Asia had previously expected to retain a long-term competitive advantage.
- Rapid progress in technologies to produce composite wood products (MDF, OSB, LVL, etc.), technologies to pulp mixed tropical hardwoods and the emergence of hardwood chips as a major international traded commodity for both industrial raw material and fuel, will result in changes.
- Distance to market will become more important, rather than the quality of the fibre in the forest, as a result remote forests will loose their commercial attractiveness.
- The special qualities and dimensions of timber from old-growth forests will no longer justify the high extraction costs if an industry can make similar products using diverse timbers from more accessible, second cycle forests.
- Argued there will always be a demand for high-value, decorative cabinet veneer and other specialty timbers - however, this will be a small fraction of total trade and the increasing availability of attractive alternatives from temperate forests may restrict this part of the tropical timber industry.
- Growth in domestic demand is likely to outstrip demand for internationally traded products in countries such as China, India, Brazil and Indonesia.
- As these countries develop their remote areas for agriculture and minerals will push roads and railways out to the fringes, thus making the cost of timber removal competitive again.
- This will in the end increase the pressure on remote forests, as opposed to export based economies.
- The average annual timber productivity of natural forests, world-wide, is currently just under 1 m^3/ha/year; thus 4 billion hectares presently yield approximately 4 billion m^3 - a volume which could be hypothetically produced from 100 million hectares of tropical plantations.
- By portraying export-led industrial forestry as the primary threat to forest conservation (e.g., Dudley *et al*., 1995), the environmental community is `shooting itself in the foot'.

Sayer, J.A., Vanclay, J.K. & Byron, N. 1997 Technologies for sustainable forest management: challenges for the 21st century. *CIFOR, Occasional Paper* No. 12. 11pp.
- Anticipate changes in:
    - production shifting from native forest to plantations
    - technological developments allowing more efficient processing, less waste and more recycling
    - end-use products becoming less dependent on the specific wood characteristics of raw materials
    - demand increasing, but fluctuating according to technologies in non-forest sectors
    - better information for decision makers, through the integration of remote sensing, GIS, and other technologies into decision-support systems
    - more rapid shifts in loci of production and transformation as industries seek out areas of comparative advantage
    - more pragmatic and efficient options for conserving biodiversity
- Technologically there is no reason why plantations cannot supply most of the world's wood requirements by early next century.
- Demand for the few specialty products that can be obtained only from natural forests may not increase greatly, and can probably be satisfied from ecologically sensitive logging operations in areas where forests are retained primarily for their environmental and amenity functions.
- Conclude that the frontier logging of relatively remote areas in the tropics, which has been a prominent feature of the timber industry in the late 20th century, may become less important in the future.
- Technological problems which made the more highly diverse and higher wood-density timbers of Papua New Guinea and South America less attractive in the past have largely been solved.
- Expect the natural forests to become less able to compete with outputs of the rapidly expanding plantation sector in the tropics and subtropics. In contrast to rising costs and declining quality of logs from natural forests, the volume and quality of plantation material will continue to improve while technological advances in plantation silviculture and wood processing continue to lower unit production costs.
- The search continues for technologies to make high-value products out of cheap and more readily available fibre.

- At present 15% of the world's industrial wood production comes from 25 million ha of fast growing plantations, located in both tropical and warm temperate countries. High-yield forestry is a reality and the biological ability to shift most wood production to plantations exists and can be put into practice if prices of industrial wood rise high enough to justify it.
- It seems unlikely that logging of natural forests will disappear completely (COMMENT: this would be a catastrophe since the forest would have no value and thus would get replaced or destroyed for other use).
- Timber revenues represent the usual way to finance the maintenance of many other forest services.
- Wood productivity in natural forests ranges, in most cases, between 1-3 m^3/ha/year.
- In plantations growth rates of 20 m^3/ha/year are now routinely achieved with some tropical and subtropical fast-growing species, while some industrial plantations of the tropics and subtropics exceed 30 m^3/ha/year operationally.
- There is a strong case to be made for further refinement of the reduced-impact logging (RIL) technologies.
- Most of the techniques embodied in RIL are not new, the innovation relates to the economics of using these technologies and to policies and incentives to promote their adoption.
- Increased use of these techniques should lead to a reduction in environmental impacts and greater productivity during future cycles.
- Thus there is scope to promote gains to be attained by reducing damage to trees and to the soil, by minimizing breakage and waste, and by reducing capital and operating costs of machinery.
- Developments in the wood processing industries may contribute to greater efficiency and less waste in both the factory and the forest.
- Recent reviews of the extent to which biodiversity can persist in logged forests further strengthens the case that most of the world's forest biodiversity can be retained without the draconian restrictions on all forest use that have often been the rallying cry of the conservation community.

Scharpenberg, R. 1998 *Forest harvesting in the natural forests of the Congo. Forest Harvesting Case Study* No. 7. Food and Agriculture Organization of the United Nations, Rome, Italy. 68pp,

- The report presents findings of a case study on forest harvesting in natural forest of the Congo. It is part of a series of case studies published by FAO in the field of forest harvesting.
- The overall objective of the study is to contribute to the development of sustainable forest management in the tropics through the establishment of credible data on forest harvesting practices and harvesting impacts in tropical high forests.
- The study aims at the establishment of reliable data on a ground harvesting system in the tropics, using power saws, crawler tractors and wheeled skidders.
- The study has been carried out in co-operation with a large private contractor operating a concession in the Republic of Congo: about 150000 ha of closed-canopy, broad-leaved forest located in the Chaillu Massif in southern Congo, at the border to Gabon; annually harvest area is about 15000 ha; and average annual rainfall in the region is about 1800 mm.
- The case study consists of a study inventory, a harvesting performance study and a harvesting impact assessment. The size of the study area is 150 ha, subdivided into three harvesting compartments of 50 ha each. The terrain is slightly mountainous, with water courses and seasonal swampy areas between elevations.
- The average harvesting intensity is only 5-6 m^3/ha (about 1 tree/ha). The main commercial species is Okoumé (*Aucoumea klaineana*), which is a medium density timber and is used for the production of peeled veneer, mainly for plywood. The low concentration of harvestable trees plays an important role in harvesting efficiency and site impact.
- The study inventory of all trees revealed an average density of 455 trees/ha greater than 10 cm dbh, of which 3.3% (15 trees/ha) are Okoumé. The proportion of Okoumé significantly increases in the higher diameter classes. During harvesting operations, all Okoumé trees above 80 cm dbh and showing adequate stem quality are felled and removed.
- The volume of 96 Okoumé logs from 93 trees harvested in the study area was computed in order to establish losses during felling and bucking. The average net volume of all 96 logs is 5.8 m^3; the total recovery, expressed as net log volume compared to the standing stem volume (including stump, up to the first branch of the crown) is 70%.
- Out of the study area, three well defined stands totaling 59.5 ha were selected for the harvesting impact assessment; the total wood volume felled and removed from this area was 345.6 m^3 net log volume, with an average skidding distance is 403 m. Crawler tractors were used for short hauls and for concentrating logs, while wheeled skidders were used for the long haul to the landing.
- Damages to the residual stand occur during felling, skid trail construction and log skidding, and were classified for study as: crown damages, bark damages and uprooted or broken trees. - felling damages were recorded on 30 felling sites. The average damage frequency was 17.7 trees damaged per felled

tree (3 trees damaged/m^3). Damage to residual Okoumé trees was 3.3% with the majority of damaged stems in the higher dbh classes. The total felling damage for all trees was 17.3 trees/ha.
- Skidding damage occurred with an average frequency of 11.5 trees/ha. The proportion of Okoumé damaged by skidding was 2.8%. On average 212 trees/km of skid trail were damaged, of which 5.9 are Okoumé, again concentrated in the higher dbh classes. 46% of all skidding damaged trees were fully or partly uprooted. The average number of skidding damages per felled tree is 11.8 (2 damaged trees/m^3).
- In total, the number of felling and skidding damages per hectare was 29 (30 damaged trees/tree felled or 5 damaged trees/m^3 extracted).
- The overall damage frequency for Okoumé in all diameter classes was 7.2%, and of trees 40-80 cm dbh (immediate future crop trees) it was 9%. The damage frequency for all species and size classes was 6.3%.
- The soil disturbance survey revealed a total disturbed area of 8.4% of the annual coupe area: felling sites 3.8%, skid trails 2.7%, secondary roads 1.0%, primary roads 0.7%, and landings estimated 0.2%. Other facilities such as workers' camps, workshops and the private airport are not regarded since they are used as the infrastructure of several annual coupes. A more detailed soil survey on felling sites, skid trails and landings, using two disturbance classes (depending on whether mineral soil is slightly or fully exposed), shows that 0.9% of the annual coupe is seriously disturbed by skid trails and landings and other 5.8% is slightly disturbed by felling sites and skidtrails.
- Under the prevailing conditions, the observed forest operation could be called "low impact" by definition due to the low removal rate of approximately 1 tree/ha. However, as with any harvest operation, further toward the objective of sustainable forest practice are possible, by placing high priority on harvest planning and assessment.

Schmidt, R. 1987 Tropical rain forest management. *Unasylva* 39(156): 2-17.
- Productive management of many humid lowland forests is both technically feasible and economically viable.
- Plantations yield great benefits but cannot replace the functions of current natural forest areas, they are complementary with each one supplying different products and most applicable to different types of terrain.
- The average dbh increment in natural tropical forests varies with many factors, but is seldom greater than 1 cm/year and is often less.
- Thus if crop trees were 10 cm average dbh, a minimum of 40 years might be expected to maturity - if larger trees can be successfully released, logging might occur every 25-30 years.
- A forest inventory in Brazil found that the forest contained 54 m^3/ha of stems >45 cm dbh, of this 36 m^3/ha were of 28 commercial species - the experiment extraction produced 72 m^3/ha of which 64 m^3/ha were commercial.
- In Peru the VAC started at 15 m^3/ha (15 commercial species), but increased to 30 m^3/ha during the study as 20 more species became commercially viable (5 year project).
- Inventory projects in Colombia indicated 114 m^3/ha of total stem volume and 33 m^3/ha of commercial volume.
- In Suriname planned skidding trails and improved felling techniques to reduce damage to remaining trees and also reduced extraction costs - with some improvements in forest management it was predicted that 40 m^3/ha could be obtained on a 20 year logging cycle with 13.5 trees/ha being commercial.
- In Africa the net volume of logs extracted varies from 5 to 35 m^3/ha.

Schoening, J.R. 1978 Forest industry development in Southeast Asia: one company's experience and observations. *In*: *Proceedings of Conference on Improved Utilization of Tropical Forests*, May 21-26, Madison, Wisconsin. USDA, For. Serv., Forest Products Lab. p.159-164.
- Paper mainly about Weyerhaeuser's experience in Indonesia.
- Rainfall 250-350 cm/year and periods of rain for 30-60 days can stop operations completely.
- Need to ballast all major haul roads with crushed rock.
- Built all supporting infrastructure for a community in the license including housing, schools, hospital, stores, places of worship, recreation, treated water, sewage disposal and electricity.
- Good utilization of all species and log grades (quality) is the cornerstone of intelligent forest resource development and long-term management.
- In traditional operations forest stands with gross volumes of up to 150 m^3/ha produced utilized volumes as low as 20 m^3/ha.
- On a historical basis, the forest products industries in every country have followed a trend from very poor utilization, in early stages of development, to a very high utilization level as industry and the economy matures.

- As a log producer the utilization level could be improved through employing proper logging techniques, transportation facilities, and development of markets.
- Weyerhaeuser improved utilization to 60-75 m^3/ha by utilizing sinkers (10% of potential commercial species) by employing barges, developing markets for excellent quality lesser known species, and by utilizing marginal quality logs.
- A typical stand would consist of 77 m^3/ha of all species over 50 cm dbh.
- A dirt road logger (seasonal) would extract 36 m^3/ha (47% of potential volume).
- A dirt road logger operating as a contractor on a licence would extract 45 m^3/ha (58%).
- An all-weather logging operation (good infrastructure gives the ability to improve utilization and also needs the better utilization to cover fixed costs) would extract 65 m^3/ha (84%).

Seppanen, H. & Malvas, J.D. 1986 *Case study on self-loading winch trucks in the tropical high forests of Viet Nam*. Food and Agriculture Organization of the United Nations, UNDP/FAO VIE/80/019, FOPH 1986/2. 24pp.
- Tropical low elevation and flat dipterocarp forest in southern Viet Nam.
- Stand volume in trees >50 cm dbh was 54 m^3/ha (19 trees/ha), with the dominant tree size falling within the 50-59 cm diameter class.
- The minimum cutting diameter was 50 cm and 8 trees/ha could be removed (leaving 11 to 12 trees/ha >50 cm dbh as residual seed trees for future harvests).
- Chain saw felling with tree-length skidding to landings.

Serna, C.B. 1986 *Degradation of forest resources: Asia-Pacific Region.* Food and Agriculture Organization of the United Nations, GCP/RAS/106/JPN, Field Document 15. 34pp.
- The selective logging that is practiced in most tropical forests in Southeast Asia can, if properly carried out and supervised, minimize the damage to the soil.
- Projected harvest volume in the second cycle cut will be considerably lower than in the old growth forests (e.g., Taguda (1977) estimated 83.2 m^3/ha (44.5% less) available 35 years after first selective logging; and Bryan and Agaloos (1965) projected 63.6 m^3/ha (36 % less) 40 years after the first selective cut).
- Although some damage is expected in selection logging, excessive damage results from:
    - selection and marking of trees to fell and retain is made haphazardly, if done at all
    - lack of supervision in felling and off-road transport
    - rough topography and use of too powerful skidding and yarding equipment
    - payment structure encourages felling and yarding production, and does not give sufficient compensation for minimizing damage to residuals or environment
- An additional source of damage that has been increasing alarmingly, at least in the Philippines, is illegal cutting.
- The end to the problem of illegal logging is nowhere in sight. In fact, it has been aggravated to the extent that it is now causing havoc in forests, especially in the residual dipterocarp forests logged under a selective system.
- In the Philippines strict guidelines are prescribed for selective logging and the use of devices to minimize damage in felling and yarding is required; however, proper supervision is lacking in most cases.

Silitonga, T. 1987 *Wood residue identification at originating points of Indonesia*. Special country report prepared for the Programme on Wood Residues Identification at Originating Points of the Food and Agriculture Organization of the United Nations, The Republic of Indonesia, Department of Forestry. 42pp.
- Average road density of 15-20 m/ha is acceptable.
- Cat D7 or D8 with experienced operators used for road construction.
- Generally there is no pre-planning of skid trails.
- Skid trails are usually established by skidder operators and their assistants who also help in locating and establishing skid trails towards the densely stocked sections of a block.
- Felling done at 1.3 m from the ground (high stumps) on all marked trees >50 cm dbh.
- For trees with buttresses, the felling cut can be 20 cm above the main buttress.
- Diameter at which topping occurs depends on market conditions.
- Study 1 - waste wood was 12% & 22% stem wood in cut-over, 11% & 17% left at collection sites.
- Study 2 - 12% & 18% waste in felling and bucking areas, 2.9% & 2.5% in log yard.
- Broken and defective logs were the major part of the wood waste, and accounted for 15.5% when calculated on a clear bole basis and slightly higher at 17.5% when based on minimum 30 cm diameter.
- Study 3 - waste wood based on a clear bole basis was found to be 25.1% for Kalimantan and 21.9% for Sumatra (less here because closer to market, therefore, higher utilization rate).

- Study 4 - the average waste wood was 19 m^3/ha (waste wood defined as: (1) part of the felled trees (stump, clear bole stem, etc.,); (2) defect trees due to improper felling; (3) the trees destroyed by tractor skidding. The minimum length considered was 1 m and minimum diameter was 10 cm inside bark.) - the lower value is due to omission of short under 1 m long waste. Study was done in Sumatra.
- For clear bole the waste wood in tropical rain forest is from 24-26% (based on (stumpage volume - extracted volume) / stumpage volume * 100).
- To a 30 cm diameter the corresponding waste wood figure is 32-35%.
- For mangrove forest it is 9% and for teak forest 11%.
- Both large and small sawmill lumber yield is 45% and waste is 55% (sawdust 10%, slabs 25%, log trim 17%, others 3%).
- Plywood mills yield 40% and waste 60% in 1981.
- Recent study showed plywood mill waste to be 45% (round up veneer now used in core, resulting in a waste reduction up to 7.4%).

Silva, J.N.M. 1992 A note on Brazil's tropical rain forests under new forest management regulations. *Journal of Tropical Forest Science* 4(4): 355-356.
- Summarizes new forest management regulations, gazetted in September 1991, to be enforced by IBAMA (Brazilian Institute for Environment and Renewable Natural Resources).
- Regulations permit logging in cases where a forest inventory demonstrates that the area is capable of sustainable timber production.
- Regulations are designed to discipline logging operations to minimize damage to residual commercial trees.
- Extraction activities are to be planned and the volume extracted should be compatible with the principle of sustained yield.
- An average logging intensity of 40 m^3/ha is recommended.
- Silvicultural treatments (e.g., climber cutting, crown liberation thinning) at 10 year intervals are prescribed in the new regulations.
- A minimum cutting cycle of 20 years was initially accepted, although 30 to 40 years may be more realistic in practice.
- Timber companies are already complaining that the new regulations will raise their cost of timber production.
- Another problem is that few mills control the large tracts of land (>10000 ha) needed to sustainably supply them with logs.
- There are no notes in regard to how the enforcement will be done or will it be successful.

Silva, J.M.N., de Carvalho, J.O.P, Lopes, J. de C.A., de Oliveira R.P. & de Oliveira, L.C. 1996 Growth and yield studies in the Tapajos region, central Brazilian Amazon. *Commonwealth Forestry Review*. 325-329.
- Study of 4 sites (7 and 13 years after logging, a secondary forest, and a control).
- Crown exposure related well to increment.
- Mortality rates were higher in `weed' species, except in secondary forest where shade-tolerant species had higher mortality.
- Volume increment was 1.6 m^3/ha/year in unlogged and 4.8 m^3/ha/year in logged forest.

Sim, B.L. & Nykvist, N. 1991 Impact of forest harvesting and replanting. *Journal of Tropical Forest Science* 3(3): 251-284.
- Study of total biomass available in a previously selectively logged (1978) area in Sabah, Malaysia.
- Volume available (all species with dbh > 19 cm) at site W4 146 m^3/ha (145 trees/ha) and site W5 129.7 m^3/ha (146 trees/ha) (based on volumes transported to landings).
- Areas were clear felled and tractor tracks covered 24% of the mechanically logged watershed.

Sist, **P., Sheil, D., Kartawinata K. & Priyardi, H.** 2003 Reduced-impact logging in Indonesian Borneo: some results confirming the need for new silvicultural prescriptions. *Forest Ecology and Management* 179: 415 – 427.
- Reduced-impact logging (RIL) and conventional techniques (CNV) were compared in a mixed dipterocarp hill forest in East Kalimantan in three blocks of about 100 ha each.
- Damage was evaluated using pre- and post- harvest assessments in 24 one-hectare sample plots.
- RIL techniques nearly halved the number of trees destroyed (36 vs. 60 trees/ha). RIL's main benefit was in the reduction of skidding damage (9.5% of the original tree population in RIL vs. 25% in CNV).
- Before logging, mean canopy openness in CNV (three plots only) and RIL (9 plots) was similar (3.6 and 3.1%) and not significantly different (X^2 = 2.73, P = 0.254). After logging, the mean canopy openness was 19.2% in CNV (n=9 plots) and 13.3% in RIL (n=8 plots), and the distributions of the canopy class in RIL and CNV significantly different (X^2 = 43.56, P<0.001).

- CNV plots showed a higher proportion of measurements in the most open class ≥30% than in RIL.
- At a larger scale, the area of skid trail per unit timber volume extracted was halved in the RIL compartment ($15 m^2$ vs. $27\ m^2\ m^{-3}$ for CNV).
- However, under high felling intensity (>8 trees/ha), both stand damage and canopy disturbance in RIL approached those recorded in CNV under low or moderate felling regime. Over this felling intensity threshold the effectiveness of RIL in reducing tree damage is limited.
- In mixed dipterocarp forest where harvestable timber density generally exceeds 10 trees/ha, a minimum diameter felling limit is clearly insufficient to keep extraction rates below 8 trees/ha.
- Based on these new results and previous studies in Borneo, three silvicultural rules may be suggested: (1) to keep a minimum distance between stumps of ca. 40 m, (2) to ensure only single tree gaps using directional felling, (3) to harvest only stems with 60 – 100 cm dbh.
- Foresters, policy makers and certifiers should consider these as criteria for sustainable forest management. There is a need to expand harvesting studies to look at impacts and trade-offs across larger forest landscapes, to expand RIL beyond silvicultural concepts and to include the maintenance of other forest goods and services.

Sist, **P. & Nguyen-The, N.** 2002 Logging damage and the subsequent dynamics of a dipterocarp forest in East Kalimantan (1990-1996). *Forest Ecology and Management* 165: 85 – 103.
- The effects of logging damage on forest dynamics processes were assessed in a lowland dipterocarp forest of East Kalimantan, Indonesia.
- From 1990 to 1991, twelve 4 ha plots (200 m x 200 m) each divided into four 1 ha subplots were set up and all trees with dbh ≥ 10 cm measured and identified at least at the generic level.
- Logging was carried out from November 1991 to March 1992 in nine plots while three plots served as control.
- The 48 subplots were grouped according to the proportion of remaining basal area after harvesting, as follows: group 1 with more than 80% of the original basal area remaining, group 2 with 70 – 79%, group 3 with less than 70%, and group 4 as control plots.
- Remeasurements were carried out just after logging in 1992and then every two years until 1996.
- Felling intensity varied from 1 to 17 stems ha-1 (50-250 m3 ha-1).
- In primary forest, mean annual mortality remained constant to 1.5% per year throughout the study period while mean annual mortality rate was significantly higher in logged-over forest (2.6% per year). This higher rate resulted from a higher mortality of injured trees (4.9% per year).
- Four years after logging, mortality rates in logged-over and primary forest were similar.
- Recruitment remained constant at 8 trees ha-1 per year in primary forest and varied from 14 – 32 trees ha-1 per year in logged-over stand in proportion with the amount of damage.
- In stands with the lowest remaining basal area, the establishment and growth of dipterocarps was strongly limited by the strong regeneration of pioneer species.
- This study suggests that total basal area removed by logging in primary forest (harvested trees and trees killed during felling and skidding) should not exceed 15% of the original one; reduced-impact logging (RIL) techniques applied with a maximum harvesting intensity of 8 trees ha-1, can keep logging damage under this threshold.

Sist, P., Bertault, J.G. & Picard, N. 2002 Why minimum diameter cutting alone cannot fit with RIL objectives. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- Because mixed dipterocarp forests exhibit high densities of timber trees, selective logging based on the minimum diameter cutting rule leads to high felling intensities from 10-20 trees/ha and high extracted volumes of 100-150 m^3/ha .
- Under such high logging intensities, RIL objectives cannot be achieved, in terms of damage reduction, yield sustainability and biodiversity.
- Using the model STREK six felling cycles were simulated under constant time t and constant extracted number of trees and applied several rotation lengths varying from 20 to 100 years with the following intermediary values: 24, 28, 32, 36, 40, 50, 60, 70, 80 and 90 years.
- The extracted number of trees was the mean number of felled trees in the three groups of damage: 6 stems/ha for G_1, 8 trees/ha for G_2 and 14 trees/ha for G_3.
- The extracted volumes (G_1 = 44 m^3/ha, G_2 = 78.5 m^3/ha, G_3 = 130 m^3/ha) were calculated based on the average volume of dipterocarps in each dbh class tabulated in Favrichon and Cheol (1998).
- In G_1, G_2 and G_3, the shortest sustainable rotations were respectively 23, 41 and 92 years, and significantly different.
- These rotation cycles give mean harvesting volumes of 2.4 m^3/ha/yr, 2.0 m^3/ha/yr and 1.4 m^3/ha/yr respectively in G_1, G_2 and G_3.

- There is a strong impact of logging damage intensity on forest dynamics: the higher the damage the longer the time of forest recovery.
- After logging, density of pioneers increases proportionally with the amount of damage; the most damaged stands show the highest density of pioneers. Results suggest that 30 years after logging, pioneers enter a phase of senescence to reach their original density recorded before logging at about 80 to 100 years after logging.
- Commercial species face drastic shifts in their density and structure.
- Their capability to adapt to altered environmental conditions created by logging and to maintain populations in the ecosystem after logging will depend mainly the original population density, population structure, regeneration dynamics and breeding systems.
- RIL clearly failed to reduce felling damage on the forest stand significantly.
- Skidding damage on residual trees decreased from 25 percent of the original stand in CL to 9.5 percent in RIL.
- The proportion of trees destroyed during logging is reduced significantly in RIL by 40 to 50 percent in comparison with CL techniques.
- In two experiments in Indonesia (Berau and Bulungan), the proportion of trees destroyed and damaged in RIL plots under the high felling intensity (n >8 trees/ha in Berau, n >9 trees/ha in Bulungan) was similar to that recorded in CL; in both techniques, this affected about 50 percent of the original stand.

Sist, **P**. 2001 Why RIL won't work by minimum-diameter cutting alone. *ITTO Tropical Forest Update* 11(2) : 5.

- The integration of silvicultural principles and guidelines is essential for improving RIL techniques towards sustainable harvesting practices.
- Four of these silvicultural principles are: (a) minimum diameter cutting limit based on stand structure (b) Minimum spacing distance of 35 m between harvested trees (c) Single-tree felling gaps and (d) maximum diameter cutting limit.
- These principles aim at keeping extraction rates below set thresholds; limit the impact of harvesting on the stand and maintain timber species populations.

Sist, P., Nolan, T., Bertault, J.-G. & Dykstra, D. 1998 Harvesting intensity versus sustainability in Indonesia. *Forest Ecology and Management* 108 (3): 251-260.

- In East Kalimantan, impacts of conventional logging and reduced impact logging on forest ecosystems were compared.
- There was a positive and significant correlation between the portion of trees damaged by felling and the harvest intensity.
- Logging intensity ranged from 1 to 17 trees/ha (9-247 m^3/ha) and averaged 9 trees/ha (86.9 m^3/ha).
- With RIL techniques, logging damage to the residual stand could be reduced by 50% when compared to conventional logging operations.
- Above a felling intensity of 8 trees/ha the effectiveness of RIL in limiting damages to the residual stand was significantly reduced, mainly due to the increasing felling damage.
- Leaving only few potential crop trees will result in a seriously depleted residual stand.
- With high harvest intensities, a sufficient harvesting volume will not be reached within the cutting cycle of 35 years.

Sist, P. & Bertault, J.G. 1998 Reduced impact logging experiments: impacts of harvesting intensities and logging techniques on stand damages. In: Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantan. Cirad-foret. 1998.

- This article describes the results of a reduced impact logging study in East Kalimantan, Indonesia.
- Three options were analysed (conventional logging, reduced impact logging with felling limit 50cm and 60cm respectively).
- The main cause of mortality was uprooting during skidding and felling (76.5% and 10.1% respectively).
- Stem breakage mainly occurred during felling (8.1%) and less frequently during skidding (3.7%).
- On average logging affected 34.4% of the area (felling 16.4%, skidding 23.6%).
- Implementing RIL techniques did not reduce felling damage.
- In this study logging damage was reduced from 48.8% in conventional logging to 30.5% in RIL (felling limit 60cm).
- The different logging intensities studied when implementing RIL techniques did not have a significant impact on the level of logging damage.
- Only 53.7% of the volume felled were extracted from the forest.
- Timber volume extraction must be limited to 80 m^3/ha to achieve the positive effect of environmentally sound logging methods.

Sist, P. 2000 Reduced impact logging in the tropics: objectives, principles and impacts. *International Forestry Review* 2(1): 3-10.

- Compared with conventional logging operations (CL) the main costs of RIL arise in the planning stage.
- Barreto *et al.*1998 demonstrated in the Brazilian Amazon that implementing RIL could result in a net financial benefit of US$ 3.70 per m^3.
- Africa: Logging intensity 1-2 trees/ha or 15-20 m^3/ha; generally less than 10% of the original tree population damaged during logging. Successive felling at a very short interval associated with poor forest inventory as practised in Africa is not compatible with sustainable management.
- South East Asia: Logging intensity 8 trees/ha or 80-100 m^3/ha; more than 50% of the original tree population are damaged during logging.
- South America: Logging intensity 5-6 trees/ha or 30-50 m^3/ha; 25-40 % of the original tree population are damaged during logging.
- Timber species are not uniformly distributed throughout the forest and logging intensity can therefore vary significantly within the same locality.
- In Malaysia, in a forest with high climber density (n=376/ha, dbh >2cm), Appanah and Putz (1984) observed that vine cutting prior to logging reduced the number of trees pulled down during felling by 50%.
- In contrast in Sabah, in a forest with a lower climber density (n=189/ha), Cedergen (1996) demonstrated that vine cutting had no effect in reducing the felling damage.
- Techniques capable of significantly reducing felling damage to stands are not yet available in the tropics. The only method of reducing such damage that is currently available is to limit the harvesting intensity.
- Trees damaged by logging show a much higher mortality than undamaged ones.
- Forests harvested with RIL may recover faster (canopy openings create favourable conditions for regeneration), so that the felling cycle may be reduced in consequence.
- The long-term benefit of RIL may arise mainly in the reduction of the felling cycle.

Skorupa, J.P. & Kasenene, J.M. 1984 Tropical forest management: can rates of natural treefalls help guide us? *Oryx* 18(2): 96-101.

- Study of the effects of selective timber harvesting on natural treefall rates in the Kibale Forest, Uganda.
- Results indicate that levels of destruction typical of capital intensive mechanized timber harvesting seriously disrupt the dynamic balance of the forest.
- The Kibale Forest has been managed as a timber reserve with a planned felling cycle of 70 years.
- Summary of logging intensity, stand conditions after selective logging and natural tree falls:

	K30 - control	K14 - medium	K15- heavy
Area, ha	300	390	360
Logging intensity, m^3/ha		14	21
Years since logging		12	12
Stems/ha	256	267	125
Basal area, m^2/ha	35.5	26.7	19.0
Canopy cover @ 15 m, %	72	50	32
Treefall rate per year[1], %	1.4	1.3	6.2

[1]Percent of all stems 9 m or more tall

- The highest rate of tree falls was in the heavy logging intensity site.
- The link to higher tree falls is most likely a change in forest structure that affect factors such as aerodynamic roughness, windbreak protection by neighbouring trees, and soil cohesion.
- Conventional mechanized logging operations that destroy up to 50% of the original forest stand are not a sustainable method for exploiting the Kibale Forest.
- The maximum allowable basal area reduction in selective logging was projected to be 35% to maintain natural treefalls at an acceptable level.

Smith, J. & Applegate, G.B. 2002 Trading forest carbon to promote the adoption of reduced impact logging. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- This paper focuses on the potential for using carbon trading to stimulate adoption of reduced impact logging (RIL)-based sustainable forest management.
- While the incremental carbon benefits of improving harvesting alone may be rather limited, significant carbon benefits could result if carbon payments could support sustainable forest management in a favourable policy and institutional environment.

Sommer, A. 1976 Attempt at an assessment of the world's tropical moist forest. *Unasylva* 28(112-113): 5-24.

- Under the influence of a euphoric belief in its unlimited growth, the area of tropical moist forests was seen until recently as an almost infinite resource, covering vast expanses of our planet and just waiting to be exploited or put to some other use.
- For the first time it became important to attempt an appraisal of the situation at the global level.
- At this point the difficulties began. The people involved in the task of gathering information were suddenly handicapped by an overabundance of data - a voluminous mass of confusing reports, scattered all over the world, yielding very few facts.
- Various survey and inventory methods were developed and applied, generating abundant, heterogeneous and dispersed information. These traditional surveys were, and still are very costly and of limited use, for selected areas.
- The global appraisal of tropical moist forests undertaken at this time can only base its research on the material available - a mass of incomplete data and a number of assumptions.
- The research consists of estimates of a varying degree of reliability - their exactitude should not be overvalued.
- Summary of the major inadequacies characterizing the documentation are as follows:
    - the required information is not available in the countries concerned
    - not all existing information at country levels is available at FAO Headquarters
    - existing and available information is often obsolete, not relevant or too uncertain
    - available information is dispersed in various documents handled by different working units
    - the definitions and terms used in country appraisals vary considerably and it is very difficult to synthesise them
    - data from forest inventories refer often only to a selected area and are not representative of whole countries
    - repeated surveys for an assessment of current changes are still very rare
    - the same figures are repeatedly used in various reports and statements without knowledge of their origin and accuracy
- Based on general considerations in different forests the annual growth potential can be estimated to be 1-2 m^3/ha/year for Africa, 1-3 m^3/ha/year for Latin America and 2-4 m^3/ha/year for Asia.
- The real annual exploitation including all the illegal activities not reflected in the statistics must comprise far larger quantities removed.
- The direct impact of exploitation varies widely and depends on the intensity of the fellings - slightly modified forests by only one felling to nearly completely destroyed stands through consecutive felling may be found.
- From 1964-73 (10-year period) an average area of 4.6-7.2 million ha per year may have been affected, based on the officially reported production - all the illegal fellings, in particular in Latin America and Asia, are not reflected in these figures.
- It may be concluded that in 1973, 0.6-1.0% of the total actual area of tropical moist forest has been affected by the officially reported exploitation for the officially reported round wood production (without fuelwood). The unknown areas under illegal felling activities have to be added to these figures.
- Areas affected through exploitation (based on round wood production 1964-1973):

	Round wood production 1964 (1000 m^3)	**Areas affected by exploitation (1000 ha)**	**Round wood production 1973 (1000 m^3)**	**Areas affected by exploitation (1000 ha)**	**Increase in percentage of areas affected from 1964**
Africa	24192	2400	31380	3200	33.3
Latin America & Caribbean	17435	600-1700	25451	800-2500	46.0
Asia	41875	700-1400	91815	1300-3000	119.2
Total	83502	3700-5500	148646	5300-8700	78

Stoeger, N.E. 1988 Waldinventur und Nutzungsplanung im Plan Piloto Forestal de Quintana Roo, México. Universitaet Goettingen. 1988. 96pp.

- For 1986 the following production costs were recorded: furniture wood production costs 25,000 Pesos/m^3, secondary wood production costs 1,817 US$/$m^3$.
- The costs for pre-harvest inventory were estimated at 252 US$/$m^3$ (1-1.5% of the revenue).
- With a cutting cycle of 15-20 years, 0.5 to 1 tree can be harvested per hectare.
- Felling and skidding cause canopy gaps of 200 to 350 m^2 per tree felled.

Stokes, B.J., Higuchi, N., Hummel, A.C., De Freitas, J.V. & Malinvoski, J.R. 1997 Harvesting in the Várzea forests of the Brazilian Amazon. *In*: *Proceedings of the FAO/IUFRO Satellite Meeting held in conjunction with the IUFRO XX World Congress*, Tampere, Finland, 4-5 August, 1995, Research on Environmentally Sound Forest Practices to Sustain Tropical Forests. Food and Agriculture Organization of the United Nations. P.47-56.

- Wet, flood areas of the Amazon.
- Average tree diameter at stump height was 1.1 m, average height was 44.4 m and average log volume was 11.1 m^3.
- Sustainable tropical forest management requires economically and environmentally acceptable harvesting practices.
- 140 m^3/ha of all trees >20 cm dbh, but only 43 m^3/ha for potential commercial species.
- Estimated diameter of selected trees at least 50 cm.
- Stump height was always above 1.5 m, but could be higher depending on the buttress.
- Gap size after felling averaged 845 m^2, or twice as large as the average on the terra-firme forest.

Sundberg, U. 1978 Implications of improved utilization of tropical forests on harvesting and transport. *In: Proceedings of Conference on Improved Utilization of Tropical Forests*, May 21-26, Madison, Wisconsin. USDA, For. Serv., Forest Products Lab. p.167-173.

- The cost per unit of wood is greatly influenced by changes in harvested volumes per unit area in the range of 5-50 m^3/ha, whereas above 50 m^3/ha the cost differentials are much smaller.
- The relative logging cost for logging intensities less than 20 m3/ha escalates rapidly (exponentially) with reducing volume.
- Breakdown of inputs (costs) by main work operations in tropical forests (all values in percent):

Work operation	**Share of cost**	**Share proportional to**			
		Unit basis, m^3		**Area basis, m^3/ha**	
		Partial	**Total**	**Partial**	**Total**
Surveying & mapping	10	20	2	80	8
Felling	5	90	4.5	10	0.5
Extraction	15	30	4.5	70	10.5
Feeder roads	15	20	3	80	12
Access roads	15	40	6	60	9
Hauling	20	30	6	70	14
Management & supervision	20	40	8	60	12
Total	100		34		66

- Above 100 m^3/ha any cost advantage associated with logging intensity may very well be offset by other influences not considered in the cost calculation.
- Infrastructure in tropical countries is often rudimentary, and its construction can cost as much as the investment cost in a mill itself.
- Increase in utilization is gradual, and since the next harvest is 30-60 years in the future the character of the operations remains a "cut and get out" type or exploitation cut.
- Increase in utilization can also be linked to other processing technologies (e.g., pulp and paper).
- The distance from the forest resource to the mill site bears strongly on cost and profitability.

Sundberg, U. 1983 Logging in broadleaved tropical forests: facilities and techniques to improve utilization in Indonesia, Malaysia and the Philippines. *Food and Agriculture Organization of the United Nations, FO:RAS/78/010, Working Paper* No. 27. 33pp.

- When extracting lower value smaller and lesser known species a minimum logging intensity of 20-30 m^3/ha is required for the operations to remain economical.
- Road densities in moderate and hilly terrain logged by tractors and managed on a sustained yield basis are often from 10-20 m/ha, with 15 m/ha as a good average (= 667 m road spacing).
- This road network is comprised of artery/main roads (20%), secondary/area roads (20-30%) and feeder roads (50-60%).

Sundberg, U. 1987 *Study on the environmental impacts of forest utilization. Food and Agriculture Organization of the United Nations, Rome, Proj. Rep. TCP/FIJ/6652*. 37pp.

- Study of two logging concessions in Fiji.
- Payment rate based on production results in excessive forest residue.
- This is because it encourages the maximization of gross daily production without regard to logging damage, improper bucking of logs and other poor practices.
- Forest is mixed tropical hardwood with a stocking of around 200 m^3/ha, of which around 50 m^3/ha is merchantable wood above the minimum allowable limit of 35 cm dbh.
- 40 species presently used.

- A few trees of the most valuable species have a stem volume up to 15 m^3, however, the average for most full bole lengths delivered to the mill is around 1 m^3.
- Past logging was unplanned without any appreciable reconnaissance, and little attention paid to the proper alignment of roads and strip roads, and environmental care was greatly neglected.
- The financial position of the entrepreneurs is weak and there is no incentive for investments in infrastructure (or environmental protection) from which others might benefit after the completion of the coupes.
- Fiji Forest Industries (FFI) has greatly improved these procedures, aiming at higher efficiency, environmental care and also a more long-term view of the operations.
- Area 1 the actual bulldozing of soil was minimal; trails had revegetated rapidly and erosion almost completely ceased 1-2 years after logging, with the exception of steep strip road sections and at the landings; if trees are not felled into streams there is no environmental damage to the soil. · Surveys of logged areas indicated that soil disturbances are moderate, but acceptable.

Suparma, N., Harimawan & Hardiansyah, G. 2002 Implementing reduced impact logging in the Alas Kusuma Group. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- In 1995, the Alas Kusuma concession of PT Sari Bumi Kusuma (SBK), collaborated with the USAID-funded Natural Resource Management Project (NRMP) in conducting an operational trial in which some RIL components were implemented.
- One of the main objectives of this study was to evaluate differences in productivity and environmental impact by pre-planning harvesting activities and exerting a tighter control over felling and skidding.
- The potential for improved harvesting economics, combined with obvious beneficial environmental results, as indicated by the initial SBK trial, prompted Alas Kusuma to attempt to duplicate this operational experiment on a slightly larger scale on its PT Suka Jaya Makmur (SJM) concession in West Kalimantan.
- Results indicated that if large-scale adoption of RIL was to succeed, a number of significant improvements and changes still had to be made in the way the company organized its activities and in the technical competence of its staff.
- The company carried out informal 'in-house' workshops where results were presented and discussed.
- The staff was also able to discuss the problems and challenges which still need to be overcome before full adoption of RIL is achieved.
- The company's existing contour maps were used as a basis for planning a systematic harvest on a 25 ha area.
- Skid trails were planned, located and opened prior to the start of felling activities. ▪ Results suggested that there was the potential of increasing productivity and reducing environmental impact through the adoption of improved operational planning and control.

Supriyatno, N. 1993 *Das Forstliche Wegenetz im Konzessions- und im Plantagengebiet im Vergleich am Beispiel des Forstbetriebes Pt. Inhutani II in Pulau Laut, Suedkalimantan, Indonesien*. Master-Arbeit. Universitaet Goettingen. 1993. 89pp.
- This study was carried out in southern Kalimantan, Indonesia.
- With unplanned skidding operations, skid trails and log landings affected 10.6% of the study area.

Tabudar, E.T. 1984 The sustainability of Philippine forests. *Asia Pacific Timber Industries*, Oct. p.26-36.
- A report with supporting field data which shows that a commercial forest industry can make a profit and at the same time protect the integrity of the environment and practice sustainable operations.
- With adequate protection the second forest can return to almost its original form.
- From growth and yield data it is expected that the AAC will be maintained at 40,000 m^3 on a cutting cycle of 35 years.
- From the study of 33 years after logging 123.5 m^3/ha was available of all species in the 60 cm and above dbh classes.
- Growth modelling has projected the third growth volume to be 322 m^3/ha (>20 cm dbh), vs. 200 m^3/ha in second growth and 261 m^3/ha in original stand.
- Timber poaching and shifting cultivation have be controlled, as well as the urge to relog areas close to the mill before the full cutting cycle time was up.
- They have no problem of meeting the government requirement that the second growth forest should yield a minimum of 67 m^3/ha.

Tay, J., Healey , J. & Price, C. 2002 Financial assessment of reduced impact logging techniques in Sabah Malaysia. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- The study was conducted as part of a project located in the Sabah Foundation forest concession area in Sabah, Malaysia.
- The pilot phase of the project comprised 1 400 ha and lasted three years from 1992 to 1995.
- In 1996, the project area was expanded by another 1 000 ha.
- The objective of the financial assessment was to compare RIL with CL in terms of costs and benefits.
- The assumption is that observed post-logging differences between RIL and CL can be attributed to the different logging methods rather than to variations between the sites.
- The data were generated directly in the study area through the establishment of a network of growth and yield plots. Eight forest management units totalling 406 ha were divided into four pairs. In each pair, one unit was subjected to RIL and the other to CL during 1993 and 1994.
- The analysis covered two cutting cycles at year 0 (t0) when the first harvest was undertaken in the primary forest, and at year 60 (t60) when the second harvest will be made.
- Prior to harvest, total stem densities for trees greater than 1 cm DBH in the CL and RIL units were 4 382 and 3 798 trees/ha.
- The original stand structure did not differ significantly for the six DBH classes (1-5, 5-10, 10-20, 20-40, 40-60, >60 cm DBH) except for trees with 1-5 cm DBH.
- The mean volume of timber extracted in the RIL and CL units of 106 and 136 m^3/ha, respectively, was within the extraction intensity of 40-160 m^3/ha reported in other parts of the study area.
- Of the 176 ha allocated to the CL units for logging, almost all of the area was logged.
- In RIL units, only 129 ha (56 percent) of the 230 ha was logged.
- The net timber volume foregone in RIL amounted to approximately 35 m^3/ha.
- The benefit of directional felling was most evident for trees in the 5-40 cm DBH range where the remaining stem density was higher in the RIL units compared with the CL units.
- In extracting 9 to 13 trees of above 40 cm DBH, the overall damage inflicted on the residual forests averaged 60 percent and 30 percent in the CL and RIL units, respectively.
- The total area of skid trails, log landings and roads in the RIL units was only 40 percent of that in the CL units.
- They represented approximately 7 and 17 percent of the total area logged in the RIL (129 ha) and CL units (175 ha), respectively.
- All three categories of openings (skid trails, log landings and roads) in the RIL units were smaller than in the CL units, but only skid trails showed a significant difference in area between the treatments.
- RIL units had a smaller area of skid trails occupying 4 percent of the total area logged compared with 12 percent in the CL units.
- The net contribution of RIL from the first harvest (t_0) was less than half of CL.
- The lower NPV_{RIL} was due to high extraction costs, and a lower yield.
- RIL costs 18 percent more than CL.
- The bulk of the additional cost comprised extraction costs at RM18/m^3 or 12 percent of CL.
- Harvest yield at t0... RIL=106 m^3/ha CL=136 m^3/ha.
- Harvest yield at t60... RIL=111 m^3/ha CL=85 m^3/ha
- For the second harvest (t60), RIL and CL yielded RM223/m^3 and RM289/m^3 respectively, without discounting. The reduction in profit due to the adoption of RIL was 23 percent of CL.
- For the first harvest, the profits generated from using RIL and CL were RM2 912/ha and RM7 715/ha, respectively.
- The 62 percent lower profits for RIL were due to lower harvested volumes. However, if only extraction activities were considered, RIL costs RM344 more than CL (RIL = RM9 573 and CL = RM9 917).
- For the second harvest, the NPVRIL and NPVCL without discounting were RM24 701/ha and RM24 554/ha, respectively.

Tay, J., Healey, J.R. & Price, C. 2000 *Pricing Carbon Retention by means of Reduced Impact Logging: a case study from Sabah, Malaysia*. University of Wales, Bangor, UK.

- The study area is located in Sabah, Malaysia.
- This study was carried out in dipterocarp forest with a high density of commercial logs.
- RIL can be used to reduce adverse carbon fluxes.
- Organisational and operational expenditures increase when implementing RIL.
- At the second cut (60-year cutting cycle) greater yields are expected from RIL areas than from CL areas.
- Revenue will be foregone through the lower timber volume logged with RIL techniques.
- With RIL, 59.4 m^3/ha were harvested.
- With CL, 135.2 m^3/ha were harvested.

- Following logging, 50% of the logged material is assumed to be converted to timber products.
- The mean carbon storage over a 60-year cycle is -38.39 tonnes per logged hectare with RIL and -94.31 per logged hectare with CL.
- Break-even carbon prices (US$/tonne) under various circumstances:

	Level of Analysis			
	Per representative hectare	**Per logged hectare**	**Per m^3 logged Scenario I**	**Per m^3 logged Scenario II**
Mean carbon storage	46.60	4.27	-40.50	-20.58
Discounted at 2%	38.42	22.04	3.63	9.62
Discounted at 4%	37.50	32.42	25.37	27.22
Discounted at 6%	38.43	37.82	36.90	37.44
Discounted at 8%	40.11	41.37	43.42	43.59
Discounted at 10%	42.09	44.28	47.94	48.00

- Where prices are negative, the RIL project is worthwhile, even without counting the benefits of increased carbon retention.
- Comparison with carbon prices derived in other ways shows that, using the same discounting assumptions, the costs of retaining carbon by RIL is expensive compared with most other carbon prices.
- No generalisation should be drawn from this individual study. In other circumstances RIL may provide a cheap carbon retention option. Particularly because of the potential opportunity costs associated with RIL, this outcome should not be relied upon.

ter Steege, H., Boot, R.G.A., Brouwer, L.C., Caesar, J.C., Ek, R.C., Hammond, D.S., Haripersaud, P.P., Van der Hout, P., Jetten, V.G., van Kekem, A.J., Kellman, M.A., Khan, A., Polak, A.M., Pons, T.L., Pulles, J., Raaimakers, D., Rose, S.A., van der Sanden, J.J. & Zagt, R.J. 1996 Ecology and Logging in a Tropical Rain Forest in Guyana: with recommendations for forest management. *The Tropenbos Foundation, Wageningen, The Netherlands, Tropenbos Series* 14. 123pp.

- In a lateritic area (Ekuk Compartment, Mabura Hill) logging increased the number of gaps by 50% as compared to natural forest, the increase in overall gap area was 400% because the gaps are larger in felling (12.6% of area vs. 3% in natural area).
- Average logging gap size was three times that of a natural gap.
- Less skidding activity will also lead to less soil compaction and finally, also prove to be more cost efficient (van der Hout, unpublished data).
- Gap size and orientation has an influence on almost all processes (biotic and abiotic). A small gap size is to be preferred from the point of view of nutrient loss and unwanted growth of secondary vegetation. The actual optimum size is unknown, but a single tree fall gap is to be preferred over multiple tree fall gaps.
- Report focuses on greenheart, which is a slow growing species with a rotation age >60 years. Also, the absence of medium size greenheart means that it will be a long time before a sufficient harvestable volume is available.
- Ecological reserve exploited plot - 4 ha logged for greenheart in 1988 with an intensity of 57 m^3/ha.
- Ekuk compartment plots 15 ha logged in 1990 with an average intensity of 37 m^3/ha.
- Conclusions:

1. Nutrient levels, CEC and fertilizer efficiency are very low on sandy soils. Forestry with log intensity of exploitation appears to be the best land use option.
2. Low intensity logging of 20-25 m^3/ha on sandy soils appears to have fairly little impact on the hydrological and nutrient cycle at catchment level.
3. To avoid erosion and siltation, logging should not occur in a buffer strip along creeks. Logging should also not occur on steep slopes for the same reasons, but this may depend on soil type.
4. Lack of individuals in the lower adult size classes of greenheart does not allow a second harvest after 20-25 years.
5. To compensate for low growth rate and decline in populations of commercial species relative to non-commercial species, after harvest, silvicultural treatments are necessary to ensure future commercial potential of the forest.
6. Uncontrolled skidding is a major cause of damage to the ecosystem because of:
   - destruction of seedlings, saplings and treelets,
   - soil compaction on skid trails,
   - leaching losses, which are largest on skid trails, and
   - unfavourable growth conditions due to high aluminium concentration and high acidity on trails.

7. Directional felling (herring-bone felling) should thus be used as a tool to reduce skidding impact on the forest ecosystem.
8. Gap size should be kept small, as:
    - changes in microclimate will be less,
    - establishment of most commercial climax species is likely to be best on such gaps,
    - surrounding forest may buffer losses in nutrients and water by root absorption, and
    - surrounding forest may buffer shortages in nutrients at a later stage by litter input.
9. Gaps should be evenly spaced over exploited areas as possible.
10. Some commercial species, such as Kabukalli or Futui, and many non-commercial species are favoured by larger gaps. As such, gap size will influence the future composition of the forest.

Thang, H.C. 1986 Concept and practice of selective management system in Peninsular Malaysia. *Malaysian Forester* 49(3): 249-260.
- In hill and dipterocarp forests shift to more selective management.
- Under the Malaysian Selective Management System a logging intensity of 30-40 m^3/ha on a logging cycle of 25-30 years is expected.
- Need appropriate felling limits and leaving an adequate number of medium sized trees of marketable species for natural ingrowth into commercial sizes.
- Need good inventory data (instead of an arbitrary prescription).

Thang, H.C. 1987 Forest management systems for tropical high forest, with special reference to Peninsular Malaysia. *Forest Ecology and Management* 21(1-2): 3-20.
- Same data presented in FAO 1989b.
- Based on a series of 100 continuous inventory sample plots of 0.4 ha each, and another 100 experimental cutting and/or silvicultural treatment plots the following observations have been made:
    - dbh growth (cm/year): all marketable species 0.80; dark/light red meranti 1.05; medium-heavy marketable species 0.75; light non-meranti marketable species 0.80; non-marketable species 0.75
    - gross volume growth (m3/ha/year): all marketable species 2.20; all species 2.75
    - annual gross volume growth (%): all marketable species 2.10; all species 1.9
    - annual mortality: (% of numbers of marketable species) 0.9%
    - annual ingrowth: (% of marketable species growing-in over 30 cm dbh limit) 0.6%
- Preliminary studies have assessed felling damages to remaining intermediate-sized trees (30 cm and above dbh) to be about 30%, with wastage due to breakage and buckling in the range of 6.5-8% of the gross timber volume.
- Percent damage by dbh class in SMS (>60 cm = 20%; 45-60 cm = 30%; 30-45 cm = 40%; 15-30 cm = 50%).
- Cutting cycle 25-30 years and the cutting limit should not be below 50 and 45 cm dbh, for dipterocarp and non-dipterocarp species, respectively.
- Should also be a minimum of 32 trees/ha left in 30-45 cm dbh class with good form of marketable species.
- The minimum net economic cut should be in the range of 30-40 m^3/ha of currently commercial and utilizable timber.
- To account for harvesting losses such as felling breakage, defects, high stumps, and short logs left in the forest the potential net volume extracted is 60% of the gross volume for trees have dbh <60 cm and 70% for trees have dbh >60 cm.
- With average annual growth rates of trees >30 cm dbh of 0.8-1.0 cm diameter and 2.0-2.5 m^3/ha in commercial gross volume, about 75% of the hill forests are capable of producing every 30 years about 40-45 m^3 net per ha, which is about the current average logging intensity in virgin hill forest.
- It is imperative to curtail exploitation damage to the residual stand to not more than 30% of intermediate-sized trees (30-45 cm dbh).

Thinley, U. 2002 Reduced impact logging in Bhutan. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.
- Prior to the early 1970s, logging was carried out manually and impacts on the soil, the residual stand and hydrology were high.
- Bhutan has endeavoured to achieve high standards of environmental protection by adopting more appropriate management, road construction and harvesting techniques.
- Bhutan's development policies are aimed also at maintaining cultural values for its population, which is heavily dependent on the forests.
- The pursuit of these policies has required a limited amount of commercial forest exploitation in order to create revenues for national development.

- Generally, Bhutan has been successful in achieving its environmental and social development goals, partly through the adoption of appropriate technology and techniques and partly due to a clear vision that has allowed decision-makers to follow a consistent course of action.

Tinal, U. & Palenewen, J.L. 1978 Mechanical logging damage after selective logging in the lowland dipterocarp forest at Baloro, East Kalimantan. *BIOTROP Special Publication* 3: 91-96.

- In East Kalimantan mechanized equipment is used in logging operations and this practice results in considerable damage to the remaining stand, particularly to seedlings and saplings.
- 25 trees/ha removed (trees removed in 4 ha area: 14 in 14-29.9 cm dbh class; 6 in 30-49.9 cm dbh class; 19 in 50-69.9 cm dbh class; 60 in over 70 cm dbh class).
- All residual trees with dbh >14 cm were recorded for logging damage (total 958 residual trees or 240 trees/ha)(165 dipterocarp and non-dipterocarp trees left or 41 trees/ha).
- 50.1% of residual trees had no damage.
- 13.68% of the trees were overgrown with climbers (can weaken or deform trees).
- 1.67% of trees had bark damage.
- 5.22% of trees had crown damage.
- 0.73% had bark and crown damage.
- 28.6% of trees were fallen or broken-off.
- 41 (commercial species) trees/ha (13 dipterocarp/ha) left after logging.

Tuomela, K., Kuusipalo, J., Vesa, L., Nuryanto, K., Sagala, A.P.S. & Ådjers, G. 1996 Growth of dipterocarp seedlings in artificial gaps: an experiment in a logged-over rainforest in South Kalimantan, Indonesia. *Forest Ecology and Management* 81: 95-100.

- Regeneration capacity of logged-over forests has decreased because most seed-bearing trees of valuable species (of best form also) have been harvested.
- In practice, the currently applied management and harvesting systems do not fulfil the criteria of sustainable forest management.
- Age structure of natural rainforests is a mosaic patter: sporadic disturbances such as treefalls are followed by emergence of young trees in gaps thus formed.
- Dipterocarps establish an ephemeral seedling stock characterized by stunted growth and capability of staying alive for some years under the canopy. As soon as overhead light becomes available as a result of a treefall or other disturbance, seedlings commence their growth and reach the upper canopy (Whitmore 1978).
- Five different gap sizes (406, 680, 940, 945 and 1242 m^2) distributed randomly through a forest were studied.
- Height growth of *Shorea fallax* and *Shorea parvifolia* was negatively correlated with gap opening, while with competing species there was no correlation.
- Increasing gap size had a negative effect of height growth of dipterocarps.
- Pioneer species colonised to a greater extent and grew faster in larger gaps than in smaller ones - invasion of pioneer species takes place when gap size exceeds 500 m^2 (Whitmore 1975, 1978 and Brokaw 1985).
- Recommend that gap sizes smaller than 500 m^2 be used.
- In the Indonesian Selective Logging System 10-15 trees/ha can normally be harvested from natural forests during the logging operations (Lamprecht 1989).

Uhl, C. & Buschbacher, R. 1985 A disturbing synergism between cattle ranch burning practices and selective tree harvesting in the eastern Amazon. *Biotropica* 17: 265-268.

- Paragominas region of the Amazon.
- Of all the options for economic development in the Amazon region, the selective harvest of valuable timber species on a rotational basis is one of the most ecologically sound.
- Selective tree harvesting, when done carefully, usually creates 3 to 6 canopy gaps/ha that are akin to natural forest tree fall disturbances.
- Pre-existing seedlings and saplings (advance regeneration) and fast-growing pioneer trees, usually originating from seeds buried in the soil, dominate the regrowth.
- Because only the nutrient poor boles are removed (leaving nutrient rich foliage, twigs, roots) and because regeneration is rapid, nutrient loss is probably inconsequential.
- Although regeneration occurs rapidly without further disturbance, poorly done selective tree harvesting leaves the forest in an open, fuel-rich, fire-prone state.
- Fires set to control weeds in adjacent degraded pastures spread readily into and through poorly logged forests causing extensive damage, but fires reaching the edge of unexploited forests quickly die out (penetrate only a few metres).
- The effects of timber removal and pasture burning interact to produce more detrimental effects than either process acting singly.

- Taken alone, selective forest cutting (when done properly) is not a severe disturbance or cause for concern, however, factors in the study area resulted in it being more detrimental than it should be:
    - cutters are not landowners and with the use of chain saws fell all potentially harvestable trees, cutting many more than are actually harvested
    - bulldozers follow and sloppily drag undamaged boles with good form to spur roads, killing many saplings in the process
    - the end result is thousands of square kilometres of cut-up forest scarred with bulldozer tracks and laden with slash (fuel)
    - closed forest canopy is often reduced by 40%, vine forests (about 75% canopy cover) lose almost all their structural integrity as whole units of vine-knitted trees are toppled over
- As a result of careless logging a fire-resistant ecosystem is changed to a fire-prone ecosystem.

Uhl, C. & Viera, I.C.G. 1989 Ecological impacts of selective logging in the Brazilian Amazon: a case study from the Paragominas Region of the State of Para. *Biotropica* 21(1): 98-106.

- Study of logging damage caused by a modern logging system (chain saw felling and bulldozer extraction (D4C) in the eastern Amazonian municipality of Paragominas.
- Study in a terra firme forest with approximately 100 tree species/ha (>=10 cm dbh), 25-35 m tall, basal area 20-30 m^2/ha and above ground biomass of 250-300 t/ha.
- Typical logging operation removes 30-50 m^3/ha (4-8 trees/ha or 1-2% of all tree stems >=10 cm dbh) of 30-60 species.
- <u>In the first study</u> area 52 m^3/ha (8 trees/ha) were extracted, amounting to 1.7% of all trees >=10 cm dbh.
- 26% of all trees existing prior to harvest are killed or severely damaged (12% lost their crowns, 11% were uprooted by bulldozing and 3% suffered severe bark damage which may eventually lead to mortality).
- 16% of the total stand basal area was harvested, while an additional 28% of the stand basal area being destroyed or severely damaged.
- Total forest canopy cover was reduced from 80% to 43% (46% reduction), however, Amazonian forests normally have only 5-20% of their area in a gapped condition at any one time.
- There was 700 m of tractor trail in the 6.8 ha area or 13 m/ha.
- <u>In the second study area</u> (52 ha) 8% of total area scarred by tractor trails, however, in areas where there was a higher concentration of desirable species >20% of the total ground surface was scarred by tractor tracks and the canopy was totally eliminated:
    - 178 m/ha of tractor trails established (9250 m in 52 ha)
    - primary trails (all wood pulled to these and are accessible to flatbed trucks) were 12 m wide and 1670 m were built
    - secondary trails (spur trails off the primary trails) were 3.0 m wide and 5380 m were built
    - tertiary trails (used only once to pull out a single tree) were 2.2 m in width and 2180 m were built
- 30 species harvested and the logging intensity was 31 m^3/ha (4.3 trees/ha)
- Removal of only 3-5 m^2/ha of the basal area resulted in 34% reduction in basal area (usually 20-30 m^2/ha in preharvested stands).
- Since stumpage is cheap in the area and forest logging rights sell for 25-50 USD/ha depending on the quality of the timber and proximity to roads, the mill operators have no incentive to log carefully.
- The severe damage to mid-size trees (20-50 cm dbh) caused by careless logging, and elevated probability of windfall and ground fires in these logged stands, suggests relatively long rotation times of 75 to 100 years before the next crop can be harvested. In reality, once loggers provide access to the Pará forest, ranchers and land-hungry settlers follow close behind foreclosing the possibility of future timber harvests.
- Problems can be combated with careful logging practices and by reducing competition from non-valuable species.
- Structural reforms in regulation, enforcement and forest tenure are required to halt the reckless use of forest timber resources in the Amazon.

Uhl, C. & Kauffman, J.B. 1990 Deforestation effects on fires susceptibility and the potential response of tree species to fire in the rainforest of the eastern Amazon. *Ecology* 71: 437-449.

- Study in the State of Para.
- With the transformation of tropical landscapes to a mosaic of logged forests, cleared fields and successional forests there is evidence that we are entering an era in which fire is a dominant disturbance in rain forest regions.

- Overall the fire regime in Amazonia is changing from one characterized by very infrequent and probably low-intensity surface fires to one in which fires are relatively frequent and of potentially high severity.
- In the study area only 50 m^3/ha were harvested, while the estimated woody debris input exceeded 150 m^3/ha due to careless logging.
- The opening up of the canopy (>50% gap area) allows the fuel to dry during the dry season to a point that it will burn (e.g., 5-6 rainless days).

Uhl, C., Verissimo, A., Mattos, M., Brandino, Z. & Vieira, I.C.G. 1991 Social economic and ecological consequences of logging in an Amazon frontier: the case of Tailandia. *Forest Ecology and Management* 46(3-4): 243-273.
- 2-3 m^3 of logs are required to produce 1 m^3 of sawn wood.
- An average 2 trees/ha (16 m^3/ha) were harvested in three study areas (each about 16 ha) and trees (>10 cm dbh) damaged during logging average 52/ha or 26/tree harvested.
- Half the damaged trees were in gaps and the other half on roads and landings.
- 0.37 trees/ha were felled but not extracted as a result of defects (usually heart rot).
- Loss of canopy cover average 8.1%.
- 1.2 m^3 of wood were lost for each m^3 harvested or 9.3 m^3 lost for ever 8 m^3 harvested.
- 16 m^3/ha extracted + 3 m^3/ha felled but left + 18.6 m^3/ha destroyed = 37.6 m^3/ha bole volume loss.
- 15 months after logging had ceased, logging openings contained, on average, 63 seedlings of timber species.
- An average 127 m^3/ha of harvestable wood was present in the logged stands (often then burnt by colonists to create farms).
- On average 56 m of logging road were constructed for each harvested tree.
- The areas cleared to establish the logging roads and log loading zones were 5.5% (area 1), 5.3% (area 2) and 6.7% (area 3) (= average 5.8%).
- On average 126 m^2 of forest were cleared next to each cut tree to allow room for the logging truck (tractor) to manoeuvre.
- Canopy openings 8.1% of area.

Uhl, C., Barreto, P., Verissimo, A., Vidal, E., Amaral, P., Barros, A.C., Souza Jr., C., Johns, J. & Gerwing, J. 1997 Natural resource management in the Brazilian Amazon: an integrated research approach. *BioScience* 47(3): 160-168.
- Brazil is well positioned to dominate the tropical timber trade in the 21st century.
- In Amazonia, as elsewhere in the humid tropics, timber extraction is done carelessly and has significant impacts on forests, leading to severe canopy loss,, increased likelihood of fire, and vine and grass invasion (Johnson and Cabarle 1993, Pinard et al. 1995, Uhl and Kauffman 1990, Verissimo et al. 1992).
- Only in rare instances are forests in the Brazilian Amazon being managed sustainably for timber production.
- A review of forestry-related studies from the Brazilian Amazon showed that only 3% addressed the question of forest management, a mere 1% examined logging practices, and virtually none addressed economic and forest policy issues.
- IMAZON project.
-
- Types of logging in eastern Amazonia in the 1990s:

Model	Selectivity of timber harvest	No. of species harvested	No. of trees harvested/ha	Economic/social system
Várzea - traditional	Highly selective low impact	1-2	1-2	Paternalistic - local people
Várzea - contemporary	General harvest high impact	Approximately 50	>10	Cottage industry- local families
Terra firme - incipient frontier	Highly selective low impact	1	<1	Big business - diversified well-capitalized co.
Terra firme - new frontiers	Somewhat selective moderate impact	5-15	1-3	Small family business - from outside region
Terra firme - Old frontiers	General harvest high impact	100-150	5-10	Large family business - from outside region

- Logging often changes to high impact as frontiers age and infrastructure and access to markets improve.
- The environmental impacts of the 5th, aggressive logging style are significant - approx. 30 trees >10 cm dbh are destroyed for each tree harvested, and canopy cover is often reduced from 80-90% in pre-logged forests to less than 50% following logging (Uhl and Vieira 1989, Verissimo et al. 1992).
- Logging in Para currently results in the harvest of approximately 4000 km^2 of forest each year, producing approximately 8 million m^3 of round wood = 20 m^3/ha.
- Present day terra firme logging practices are best characterized as "forest mining", where future entries are too soon (i.e., before the forest grows and recover to preharvesting conditions) - take out lesser known species and smaller desirable species.
- In addition to vines taking up growing space they also weigh down the juvenile trees and cause bole deformities.
- Fire is another problem, with the build-up of slash and the opening of the forest.
- The end result of terra firme logging is often a highly degraded ecosystem that has lost much of its forest character - in its present guise in much of eastern Amazonia logging is really step-wise deforestation.
- Timber is under-valued and therefore used carelessly.
- One or more trees per hectare (amounting almost to 7 m^3/ha) are felled but never recovered by the skidder operations.
- Careful planning of machine movements resulted in about 25% reduction in the ground area affected by machine movements when compared to unplanned logging (Johns et al. 1996).
- Vine cutting two years before logging resulted in about 30% reduced damage to trees >10 cm in dbh (Johns et al. 1996).
- Trained loggers were able to achieve a 3x reduction in waste associated with felling and bucking (cuts closer to ground and reduced butt splitting by using correct felling procedures).
- Machine operating time was reduced by 20%.
- Girdling to kill undesirable trees after logging provided significantly more growing space for the commercial individuals targeted for future cuts.
- Added cost for extra inventories, mapping, vine cutting is about $50/ha.
- The monetary losses from ineffective use of machinery and unnecessary wood waste in unplanned operations may often be greater than the additional costs associated with planned logging operations. Hence planned logging may actually lead to increased profits.
- By have RIL can have a cutting cycle of 30-40 years with a sustainable yield with each entry instead of 70-100 years.
- Sawmill yield is only 33% of each harvested log, but could be increased to nearly 50% through simple improvements in machinery maintenance and by training the labour force.
- By increasing logging efficiency, forest management, and processing efficiency, companies would only require 1/3 of the forest land that they now require for the same sawn wood output.

Vanclay, J.K. 1989 Modelling selection harvesting in tropical rain forests. *Journal Tropical Forest Science* 1(3): 280-294.

- Paper outlines a harvesting model which enables estimation of selection logging yields and quantification of impact on the residual stand.
- Important predictors include tree species and size, stand basal area, basal area logged, logging history and topography; soil type and site quality do not appear to influence harvesting.
- Marking rules in Queensland allow defective trees down to a dbh of 40 cm to be removed, otherwise it generally varies for 60-100 cm dbh depending on the species; at least 50% canopy cover retained; directional felling to minimize damage to residual stems; seed trees retained at a spacing of at least 40 m; allow addition trees with outstanding form and vigour to be retained.
- Residual stem damage prediction equations were derived from a series of nine logging damage studies from 1977 to 1980; one of the major variables is the amount (volume or basal area) logged.
- The damage data comprised slope, relative basal area logged, soil type, logging history, species, dbh and damage which was zero if the tree survived and one if the tree was destroyed.
- In the model logging history has an impact of volume yield (less volume available), but 38 years after logging, tree marking in a previously logged stand reached the same selection intensity as in a virgin stand.

- Summary of logging damage studies:

	Number of trees	% of original stand
Base stand information		
- desirable trees marked for retention	115	3.7%
- merchantable stems not marked for removal	2145	69.8%
- unmerchantable stem	355	11.5%
- stem marked for removal, felled & removed	424	13.8%
- stem marked for removal, felled & left as unmerchantable	36	1.2%
Total stems	3075	100.0%
Damage to bark, wood and crown information		
- destroyed (dead or will die)	308	10.0%
- other (will probably survive)	353	11.5%
Total	661	21.5%

Van der Hout, P. 1999 Reduced impact logging in the tropical rain forest of Guyana. Ph.D. thesis. University of Utrecht, Netherlands. 331pp.

- This study was carried out in the Upper Demerara district of Guyana.
- Reduced impact logging was studied with harvesting intensities of 4, 8 and 16 trees/ha.
- With conventional logging an average of 8.7 trees/ha was harvested (basal area 2.2 m^2, or 27.8 m^3/ha). The variability was high (0 to 25 trees/ha harvested).
- Mean loss of canopy cover as percentage of total area:

Type of logging	Loss of canopy cover (%)	Loss of canopy cover per tree extracted (m^2)	Mean gap size (m^2)	Number of gaps per hectare
Conventional logging				
8/ha	15.8	198	264	6.0
16/ha	24.5	153	439	5.7
Reduced impact logging				
4/ha	8.5	208	185	4.6
8/ha	15.7	192	209	7.7
16/ha	30.1	184	333	9.0

- The logging method does not have a significant influence on the gap size.
- Mean ground area affected during actual skidding and other movements:

	Percentage of total area (%)		
	Trails	Other movements	Total
Conventional logging			
8/ha	8.2	4.7	12.9
16/ha	9.9	10.8	20.7
Reduced impact logging			
4/ha	4.9	0.1	5.1
8/ha	7.6	0.4	8.0
16/ha	8.3	0.5	8.1

- Ground disturbance in felling gaps occurred significantly more often in conventional logging than in reduce impact logging; an average 6.7% of the total area as opposed to an average 1.1%.
- Conventional logging severely damaged a basal area of 1.5 m^2/ha (an estimated 5.1% of the original stand) with no significant relation to logging intensity. Reduced impact logging seriously damaged a basal area of 0.5 m^2/ha (2.1% of the initial stand) after a light harvest, and a basal area of 1.8 m^2/ha (7.6% of the initial stand) was damaged with a logging intensity of 16 trees/ha.
- In the reduced impact operation a higher proportion of tree damage was due to felling than in the conventional operation. An increase in logging intensity raised the proportion of damage due to felling as opposed to skidding.
- Reduced impact logging reduced the number of trees killed by skidding by 24 trees/ha.
- During the entire operation trees between 20 and 40cm dbh were relatively more frequently damaged. This may be due to their relatively large crowns when compared to smaller size classes.
- Compared to conventional logging reduced impact logging damaged trees between 20 and 40cm dbh less frequently, large trees more frequently, and a similar proportion of the trees between 10 and 20cm dbh.
- RIL is effective in reducing skidding damage to small and medium sized trees. However, the level of felling damage increases when RIL is implemented.

- With conventional logging, 85% of the residual stand are likely to survive at a harvesting intensity of 8 trees/ha, at a harvesting intensity the rate of survival will be reduced to 77%.
- With RIL, 89% of the trees will probably survive at a harvesting intensity of 8 trees/ha (78% at 16 trees/ha).
- Survival rates are highest among large trees (92 to 96%) and lowest among small trees (71 to 87%).Directional felling did not result in a smaller number of affected commercial trees, but it may have had an affect on the severity of the damage. A positive impact of directional felling was noted in the field but could not be verified statistically. With a cutting cycle of 25 years and neglecting mortality, harvesting intensity of 8 trees/ha may be possible. However, for the following cutting cycle all trees will have to be recruited from the 20-40cm dbh size class, which will take much longer than 25 years. With the same assumptions, stand table projection with a harvesting intensity of 8 trees/ha indicate 27 trees/ha in the 40cm and above size class after 25 years, which suggests that this exploitation level may be sustainable.
- In this study RIL reduced the damage to the residual stand by 6% at an extraction level of 8 trees/ha, and by 3% at an extraction level of 16 trees/ha.
- RIL resulted in a reduction of the skid trail coverage from 13% to 8% of the total area at a logging intensity of 8 trees/ha and from 21% to 85% at an intensity of 16 trees/ha.
- Liana cutting did not seem to have any effect. However, cutting lianas 6 months prior to harvesting is probably too short a period (only 50% of the trees had died 6 months after cutting).
- Fewer composite gaps occurred with reduced impact logging.
- Due to implementation of RIL the proportion of residual trees damaged by skidding was reduced from 12% to 8% at a logging intensity of 8 trees/ha and from 16% to 9% at a logging intensity of 16 trees/ha.
- Due to implementing RIL techniques the level of felling damage was reduced from 15% to 12% at a logging intensity of 8 trees/ha whereas an increase from 22% to 24% was found at a logging intensity of 16 trees/ha.
- It was found that the number of trees irreversibly damaged by felling did not differ at a harvesting intensity of 8 trees/ha - remaining at 8% - but increased strongly at an intensity of 16 trees/ha - an increase from 12% to 18% by applying RIL techniques.
- Felling and skidding damage taken together, this equals a reduction of irreversible residual damage from 15% to 11% (at 8 trees/ha) and from 22% to 21% (at 16 trees/ha) respectively.
- In conventional logging, felling reached a productivity of 10 m^3/h per crew while in reduced impact logging productivity only reached a level of 5.8 m^3/h (reduction in felling performance 37% while the operative machine time was increased by 66%).
- For skidding the volume delivered at the landing per operative machine hour increased from 11.8 m^3/h to 14.4 m^3/h when RIL guidelines were implemented.
- Costs of pre-harvest planning for conventional and reduced impact logging in US$/ha (Costs are incurred one year prior to harvesting):

Activity	**Costs (US$/ha)**	
	Conventional Logging	**Reduced Impact Logging**
Block lay-out	2.08	2.80
Inventory	2.45	7.66
Liana cutting	0.00	3.99
Data processing	0.23	0.46
Map making	0.10	0.43
Road planning	0.20	0.20
Total	5.06	15.52

- Costs of harvest preparation for conventional and reduced impact logging in US$/ha (The road density of primary roads is 2m/ha and of secondary roads is 10m/ha. The area occupied by landings amounts to 50 m^2/ha. Costs are incurred six months prior to harvesting):

Activity	**Costs (US$/ha)**	
	Conventional Logging	**Reduced Impact Logging**
Road construction		
Primary road	6.42	6.42
Secondary road	4.61	4.61
Landing construction	3.84	3.84
Skid trial demarcation	-	2.37
Total	14.87	17.24

- Reduced impact logging thus increases the up-front costs by US$ 12.83/ha (NPV = $14.69/ha) which have to be recovered by more efficient harvesting operations.

- Cost of felling, skidding and landing operations for conventional and reduced impact logging in US$/$m^3$ and output expressed as m^3 per effective crew hour (felling and landing operations) or effective machine hour (skidding) [flat to rolling terrain, logging intensity of 10 trees/ha, standard load of 9.7 m^3 per trip, average straight-line distance 383 m]:

Activity	Conventional Logging		Reduced Impact Logging	
	Costs ($/$m^3$)	Output (m^3/h)	Costs ($/$m^3$)	Output (m^3/h)
Felling and bucking	0.60	10.6	1.16	6.7
Skidding	4.30	14.4	4.10	15.9
Landing operations	0.34	19.3	0.32	20.9
Total	5.24		5.58	

- Costs per m^3 and equivalent volume output per day of support, logistics and supervision (Estimates are based on a daily output per logging team of 84 m^3 for conventional logging and 97 m^3 for reduced impact logging, at logging intensities of 28.5 and 31.0 m^3/ha respectively):

Activity	Conventional Logging		Reduced Impact Logging	
	Costs ($/$m^3$)	Output (m^3/h)	Costs ($/$m^3$)	Output (m^3/h)
Road maintenance	1.91	167	1.64	195
Logistics	2.88	84	2.48	97
Supervisor	0.26	84	0.22	97
Cooks	0.23	84	0.20	97
Base camp	1.66	-	1.66	-
Administration costs	0.33	-	0.33	-
Royalty	2.68	-	2.68	-
Area fee	0.21	-	0.19	-
Total	10.17	-	9.40	-

- In the conventional logging operation the average volume recovered per tree amounted to 2.9 m^3 whereas a volume of 3.1 m^3 was recovered on average in the RIL operation.
- The extra investment during the felling phase in RIL was mainly benefiting the performance of the skidding phase and only marginally the higher wood recovery.
- For reduced impact logging the change in the aggregate logging cost (per m^3) is small (increase of 5%) when the logging intensity is reduced from 16 to 8 trees/ha (from 50 to 25 m^3/ha). The cost rises more strongly when the harvesting intensity is further reduced to 4 trees/ha and even more when subsequently being reduced to 2 trees/ha [the absolute financial values and differences should not be taken too seriously. The results are all based on projections from the observed situation with a logging intensity of 10 trees/ha]:

	Logging intensity (trees/ha)			
	2	4	8	16
Pre-harvest planning	2.42	1.21	0.61	0.30
Harvest preparation	2.69	1.34	0.68	0.34
Felling & bucking	1.18	1.17	1.16	1.14
Skidding	4.25	4.17	4.08	4.01
Landing operations	0.32	0.32	0.32	0.32
Trucking, loading and unloading	13.54	12.69	12.26	12.04
Road maintenance	2.12	1.82	1.66	1.57
Support, logistics & supervision	3.68	3.20	2.94	2.79
Other overhead costs	1.99	1.99	1.99	1.99
Royalty and fee	3.63	3.15	2.92	2.79
Total cost	35.83	31.08	28.62	27.30

- In the long term several benefits are associated with reduced impact logging. Attempts to place a financial value on these are neither realistic nor even desirable for that very reason.
- The financial appraisal showed that reduced impact logging is cost competitive with conventional logging. The direct costs per cubic metre may have been 12% higher, which was mainly related to higher planning and felling costs. There are strong indications that the cost of felling will be reduced in the future when the operators have gained more experience in using the felling method. In the present study, the additional costs were offset by a higher per day and per area, which reduced direct cost components such as road construction as well as indirect costs such as logistics, supervision and support.

Van der Hout, P. 2000 Testing the applicability of reduced impact logging in greenheart forest in Guyana. *International Forestry Review* 2(1): 24-32.

- The study was conducted at Pibiri in Central Guyana.
- For conventional logging two harvesting intensities (8 stems/ha and 16 stems/ha) were evaluated. Due to the clumped distribution of commercial trees the absolute logging intensity varied over the area, ranging from 0-78 m^3/ha. 96% of the extracted trees were *Chlorocardium rodiei.*
- For reduced impact logging, harvesting intensities of 4, 8 and 16 stems/ha were analysed. A harvesting intensity of 8 stems/ha corresponds to a volume of 25 m^3/ha. The share of *Chlorocardium rodiei* was reduced to 53% of the cut trees.
- It must be noted that in this case conventional logging operation featured felling in groups while trees were scattered in the RIL operation.
- RIL resulted in a greater loss of canopy if the logging intensity was increased above 8 trees/ha.
- In the conventionally logged blocks, the average canopy opening per felled tree decreased by 23% when the harvesting intensity was increased from 8 to 16 trees/ha.
- Implementation of RIL techniques reduced the area traversed by the skidder by about 2/3 depending on the logging intensity, while skidder movements in felling gaps were reduced by about 3/4 (also depending on the logging intensity).
- By adopting RIL, felling damage was reduced by 16% at a logging intensity of 8 trees/ha, whereas it was augmented by 9% at a logging intensity of 16 trees/ha.
- No difference was found in the size of single tree fall gaps. Liana cutting and directional felling as carried out in this study did not reduce the amount of canopy loss.
- Skidding appeared to have a lower impact in the RIL operation than in the conventional logging operation.
- The gross volume recovery rate increased from an average of 2.9 to 3.1 m^3 over bark by implementing RIL techniques.
- RIL reduced the felling performance by 37% while the operative machine time was increased by 66%.
- The implementation of RIL increases the skidding output from 14.4 to 15.9m^3/h.
- Cost of logging of conventional and reduced impact logging:

Operation	Conventional (US$/$m^3$)	Reduced Impact (US$/$m^3$)
Pre harvest planning	0.18	0.50
Harvest preparation	0.52	0.56
Felling and cross-cutting	0.60	1.16
Skidding	4.30	4.10
Landing operations	0.34	0.32
Trucking, loading and unloading	12.18	12.18
Road maintenance	1.91	1.64
Support, logistics and supervision	3.37	2.90
Other overhead costs	1.99	1.99
Royalty and area fee	2.89	2.88
Total	28.29	28.23

- RIL systems are neither necessarily more expensive, nor cheaper than harvesting with conventional techniques.
- RIL resulted in a very modest reduction in residual stand damage and canopy loss. Only the reduction of the skidding trail coverage is in agreement with the results of other studies.
- Residual damage in conventional operations in Guyana was lower than in most RIL operations elsewhere. Therefore the spectacular reductions in other studies should be seen against a higher benchmark.

Van der Hout, P. & van Leersum, G.J.R. 1998 Reduced Impact Logging: A Global Panacea? Comparison of two logging studies. *In*: *Research in tropical rain forests: its challenges for the future.* Tropenbos Foundation, Wageningen. Pp. 185 – 202.

- Two projects concerning the impact of reduced impact logging on the vegetation in Guyana and Cameroon are compared.
- Exploitation level was the most important damage factor as compared with logging method in both studies.
- In Guyana if felling intensity exceeds 8 trees/ha, the accumulated gap area is less in a conventional operation than in the experimental RIL operation. RIL however produces smaller mean gap sizes.
- With an intensity of 8 trees/ha, canopy loss is the same with either method, but, an intensity of 16 trees/ha, canopy loss was higher with RIL.
- Skidding damage in canopy gaps is negligible with RIL and extensive with conventional logging.

- In Cameroon large scale climber cutting did not decrease gap size nor the level of damage to individual trees.
- In Guyana liana cutting did not have any effect on canopy opening.
- In Guyana skidding damage was reduced by applying RIL, regardless of logging intensity.
- While directional felling and winching are important tool in RIL in Guyana, their application in Cameroon is constrained by the size of the trees.

Van Gardingen, P.R.; McLeish, M.J., Phillips, P.D., Fadilah, D., Tyrie, G. & Yasman, I. (*in press*) Financial and ecological analysis of management options for logged-over Dipterocarp forests in Indonesian Borneo. *Forest Ecology and Management*.

- Sustainable management of logged over forests requires an understanding of the potential yield from the forest and likely financial performance of the management system.
- The growth and yield model SYMFOR was linked to a financial model derived for a forest concession managed under the Indonesian selective logging and replanting system (TPTI).
- This combined approach was used to predict the likely timber yield for contrasting management regimes and then to calculate estimates of the financial performance described as the internal rate of return (IRR) and net present value (NPV) of the forest estate using both the TPTI system and reduced impact logging (RIL).
- The systems evaluated included one defined by a maximum of 8 harvested stems per ha and others based on maximum volume extracted of either 50 or 60 m3/ha. Cutting cycle lengths evaluated ranged from 25 to 45 years.
- Average yields from the TPTI system decreased from over 80 m3/ha for the first simulated cycle to between 35-40 m3/ha for the third and fourth harvests.
- Systems based on RIL with a cutting cycle of 35 years with yield regulated to 50 m3/ha or 45 years with a regulated yield of 60 m3/ha were the best alternatives to the TPTI system.
- The TPTI system is not economically viable after the second harvest leaving the only financially viable alternative of land conservation after clear felling of the remaining forest. ▪ RIL systems were unable to consistently achieve an IRR of 16% unless there were also decreases in waste.

van Gardingen, P.R., Clearwater, M.J., Nifinluri, T., Effendi, R. Rusmantoro, W. Noor, M., Mason, A., Ingleby, K. & Munro, R.C. 1998 Impacts of logging on the regeneration of lowland dipterocarp forest in Indonesia. *Commonwealth Forestry Review* 77(2): 71-82.

- The study was conducted in Central Kalimantan (Indonesia) in lowland dipterocarp forest. Annual rainfall is high (3500mm) with a drier season from July to October.
- The forest is dominated by members of the Dipterocarpaceae (17% of total number, 40% of basal area) and Euphorbiaceae (15% of total number, 6% of basal area).
- The average stocking density is 583 stems/ha with a basal area of 34.4 m^2/ha.
- Four scenarios were evaluated: Primary forest, manual extraction (clearfelling, processing on site, no machinery on site), conventional logging (10 trees/ha removed) and reduced impact logging (following the FAO model code for forest harvesting practice).
- Canopy cover in unlogged primary forest was uniformly high; dipterocarp seedlings were present on most of the area.
- With conventional logging, 38% of the canopy was completely removed, and logging debris or skid trails covered 52% of the area. Dipterocarp seedlings were concentrated along the margins of skid trails and felling gaps in areas with undisturbed soil and partially open canopy.
- There could be significant reductions in the level of canopy disturbance if directional felling techniques were implemented (the gap size opened by the felling of two trees ranged from 545 m^2 to 1081 m^2).
- 6 months after logging, dipterocarp seedlings were already growing rapidly in disturbed areas. The average seedling height was higher than in areas with undisturbed canopy.
- 18 months after logging, the tallest seedlings of pioneer species were higher than the dipterocarp seedlings.
- Dipterocarps appear to be highly dependent upon their mycorrhizas. Poor growth and survival of naturally regenerating dipterocarps in logged forest could be the result of the removal of host- or site-specific mycorrhizal fungi.
- Soil disturbance is usually minimal in natural canopy gaps. As a consequence, the large reservoir of ectomycorrhizal fungi within the soil and on the roots of mature trees remains largely undamaged. Dipterocarp seedlings will thus be able to quickly gain access to a wider diversity of mycorrhizal fungi.
- The lowest intensity of damage was observed when timber was manually removed form the site. After 9 months the largest seedlings were located where the canopy had been fully opened up and where, as a result, levels of mycorrhizal infection of 74% were achieved.
- The highest intensity of damage was observed in plots logged with conventional techniques. Seedlings only reached mycorrhizal infection rates of 30%.

- In primary forests (closed canopy) and natural canopy gaps infection rates of 15% and 85% respectively were recorded.
- Both the removal of mature trees and resulting soil disturbance are thought to severely limit the successful establishment of dipterocarp seedlings through their apparent impact on the mycorrhizal flora (Smits 1983).
- Data from conventional logging trials showed that seedlings were absent on 49% of the area while the soil was disturbed on 68% of the area.
- Although RIL is an improvement when compared to other logging techniques, it still leads to a reduction in both the amount of mycorrhizal inoculum available and the mycorrhizal diversity. This could affect the regeneration of particular, perhaps commercially important, dipterocarps. Therefore fine-tuning of this system may be required in order to ensure adequate regeneration.
- The mean canopy opening per felled tree is $390m^2$.
- The optimum disturbance regime for the processes of seedlings establishment and regeneration will be associated with small gaps ($<650m^2$) created by logging and extraction of no more than 2 trees per gap. Larger gaps ($>1000m^2$) may eventually inhibit regeneration of the forest either through failure of seedlings to establish or through the intense competition with pioneer species.

Vergara, N.T. 2002 Recent advances in training strategy development in support of RIL implementation. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- A necessary condition for implementing RIL is that personnel have the qualifications to perform their tasks and responsibilities effectively and efficiently.
- Personnel need to know and understand the nature and scope of the work to be done, why it has to be done and how best to do it. In combination, these skills enable them to carry out complex tasks efficiently. Thus, greater efficiency and higher productivity in timber extraction under RIL is achieved through training.
- RIL training often concentrates on felling/bucking and yarding/skidding operations simply because their negative impacts on the residual stands and the forest ecosystem as a whole are highly visible, and readily measurable in physical and monetary terms.
- This approach often fails to recognize that other key stakeholders, such as policy-makers, planners and supervisors also need to undergo training because their decisions have significant and long-term impacts on the productivity and sustainability of the forest resources.

Verissimo, A., Barreto, P., Mattos, M., Tarifa, R. & Uhl, C. 1992 Logging impacts and prospects for sustainable forest management in an old Amazonian frontier: the case of Paragominas. *Forest Ecology and Management* 55(1-4): 169-199.

- Of the 238 sawmills present in the study region in late 1989, 79% were installed during the 1980s, with average production for a one band saw mill of 4300 m^3/year.
- Lumber yield is 47 % or 2.13 m^3 of round wood produces 1 m^3 of sawn wood.
- 63% were vertically integrated with both logging and sawmilling operations.
- Average for 3 sites of 6 trees/ha harvested with a volume yield of 38 m^3/ha (range from 2.9 to 9.3 trees/ha and volume 18 to 62 m^3/ha).
- Typical extraction rates for the area ranges from 20 to 50 m^3/ha.
- 27 trees >= 10 cm dbh are severely damaged for each tree harvested (= 150 trees/ha).
- 48 uprooted, 41% broken stems, 11% severe bark damage.
- Tree damage was not in direct proportion to volume extracted (e.g., harvesting 18 m^3 damaged 5 m^2 of basal area in area 1, but in area 3 where more than 3 times more volume harvested, basal area damaged increased by 50%).
- Opening about 40 m (218 m^2 of scraped ground surface per harvested tree) of logging road and 663 m^2 of canopy opening per tree harvested.
- Natural tree falls in the region open gaps from 150 to 300 m^3.
- The biggest impediment to forest management in the eastern Amazon is the undervaluing of the timber resource (stumpage rights sold at 50-150 USD/ha).
- With careful extraction and management procedures, harvests could be accomplished on a 30 to 40-year-cycle and forest integrity could be maintained.· Early 70s loggers harvested only a few high-value species and forest impacts were small.
- 20 years later more than 100 tree species are harvested. Canopy coverage decreased for 82% in control to 40-47% in logging areas (mean 45%).Annual dbh growth increments of 0.8 cm/year (managed vine cutting and thinning treatments) and 0.3 cm/year (unmanaged) reveal that the difference in accumulated bole volume between managed and unmanaged stands, considering just commercial species >= 30 cm dbh, will be 22 m^3/ha after 35 years. Pre-extraction survey and vine cutting can reduce damage by up to 50%.Management cost would be about 5 USD/m^3 extracted, but loggers only pay stumpage of 1-3 USD/m^3 extracted.

Verissimo, A., Barreto, P., Tarifa, R. & Uhl, C. 1995 Extraction of a high-value natural resource in Amazonia: the case of mahogany. *Forest Ecology and Management* 72(1): 39-60.

- Typical one band saw mill will on average produce 4500 m^3/year of sawn wood mahogany from 9900 m^3 of round wood (45.5% yield).
- An average of 5 m^3/ha (= 1 tree/ha) of mahogany removed.
- Future mahogany cuts are in doubt because only 0.25 mahogany trees/ha of at least 30 cm dbh found on recently logged sites and no trees between 10-30 cm dbh. Mahogany seedlings were also rare.
- Logging damage is great - 31 trees >10 cm dbh were severely damaged for each mahogany tree harvested; approx. 1100 m^2 of forest ground was scraped clean or trampled for each mahogany tree removed.
- After logging there is a growing trend to convert forests to cattle pasture, in part perhaps, because the prospects for future mahogany harvests do not appear to be good.
- The other trees left after logging amounted to 31.3 m^3/ha of wood >30 cm dbh in the sawable category (only 0.3 m^3/ha of mahogany though), 13.1 m^3/ha in the potential use category, and 51.3 m^3/ha without wood-related uses (these are lower than further to the north in Para State).
- Need to encourage regeneration of mahogany through adopting measures to increase natural regeneration (at its success), plant mahogany in logged areas, and establish plantations of mahogany in open areas.
- The logging cycle for mahogany may be as long as 80-100 years (when relying on natural regeneration).

Vidal, E., Johns, J. Gerwing, J.J., Barreto, P. & Uhl, C. 1997 Vine management for reduced impact logging in eastern Amazonia. *Forest Ecology and Management* 98(2): 105-114.

- A study on vine management was undertaken in a 210 ha forest stand in eastern Amazon, Brazil.
- Objectives were to determine vine species composition, stem densities, and the abilities of different vine species to resprout following cutting.
- The degree of tree canopy connectedness due to vines and the amount of damage associated with felling trees with inter-crown vine connections as well as the costs of vine cutting as a forest management tool were assessed.
- Although vine cutting prior to logging can reduce logging damage, it costs approximately US$ 16 per hectare. This is equivalent to 8% of the profits of a typical logging-only operation.
- Reductions of the cost of vine cutting could come with the development of species-specific cutting prescriptions that would reduce the total number of vine stems cut by focusing cutting efforts on aggressive species likely to cause silvicultural problems.

Virtucio, F.D. & Torres, M.G. 1978 Status of management and utilization of forest resources in the Philippines. *The Malaysian Forester* 41(2): 149-166.

- Average volume in dipterocarp forests ranges from 100-200 m^3/ha (does not give to which minimum dbh class or species groups).
- Gives AAC equations for the various forest types under different management strategies.
- Reference to 3000 active growth plots established in various logged-over dipterocarp forests for the prediction of their growth and yield.
- Poor utilization of the hardwood forest.
- Of over 3000 tree species in the dipterocarp forest, only less than 100 are commercially utilized.
- Present practice of forest utilization leave voluminous waste and residue in the forest; for every 100 m^3 removed from the forest, 50 m^3 of logging waste and residues are generated.

Visser, R. 2002 Environmentally Sensitive Harvesting? *Virginia Forest Landowner Update* 16 (1).

- Environmentally sensitive harvesting is used to define and promote improvements in common harvesting systems.
- The forest industry needs to look towards new technologies and systems to provide the required environmentally sensitive harvesting techniques.
- Regardless of the machinery involved, it is the people that must make the decision about what harvesting strategy to use and what equipment to employ to protect water, soil, and overall forest quality.

Wagner, M.R. & Cobbinah, J.R. 1993 Deforestation and sustainability in Ghana. *Journal of Forestry* 91(6): 35-39.

- Nearly 93% of all forest land in West Africa (Benin, Ghana, Guinea, Guinea Bissau, Cote d'Ivoire, Liberia, Nigeria, Sierra Leone, and Togo) has sustained some timber harvesting.
- In Ghana soon some species will no longer exist in sufficient numbers to be used for timbers.
- Most of the commercial species respond well to low intensity harvesting (Hawthorne 1989).
- Disturbance is a natural part of the tropical forest, as it is for any forest ecosystem.

- As long as harvesting mimics the natural disturbance regimes, the tropical forests of Ghana can be sustained while being harvested.
- Greater disturbance favours pioneer species.
- Felling limit is 70 cm dbh.
- Growth 3-6 m^3/ha/year.
- Logging damage to the residual stand and unused forest residues may not be fully accounted for in the allowable cut estimates. Ghana's practice of setting allowable cuts considerably below the annual growth is prudent.
- While tropical forest growth is sustainable, it will likely occur on a different set of species than those presently being harvested.
- Longer felling cycles will reduce the degree of disturbance and lengthen the recovery period.
- The felling cycle in Ghana was recently extended from 25 to 40 years.
- Logging methods should be revised to reduce the amount of understory disturbance.
- It would be appropriate to leave residual "overmature" trees in stands as seed sources and to preserve unique habitats.
- Harvesting secondary species is often encourage - however, this could lead to greater disturbance at each forest entry, with dramatic effects on species composition.

Watanabe, S. 1992 Percentage of felling in the natural forest and damage caused by felling operations - a case of natural forest in Lokkaido, Japan. *In*: *Beyond the guidelines - an action program for sustainable management of tropical forests*. International Tropical Timber Organization, Technical Series No. 7. P.146.
- Commercial scale operation of 20,000 ha of forests (goal to produce a multi-storied natural forest that supplies high-quality timber).
- Found that it is difficult to keep the stand composition intact with selection cutting of at least 30% of the stand or more.
- When the cutting percentage reaches 65% or more, the stand composition is destroyed.
- Consequently, when a high percentage cutting is performed continuously, the forests are gradually degraded.
- Based on the above a cutting percentage (basal area assumed) of 13-17% is used.
- Has been shown that, if the natural forest is managed at a stock level of 70-80% of the climax and a low percentage of cutting (13-17%) is carried out in a short cycle (8-10 years), the total harvest volume can be increased without losing the productivity and health of the forest.

Webb, E.L. 1997 Canopy removal and residual stand damage during controlled selective logging in lowland swamp forest of northeast Costa Rica. *Forest Ecology and Management* 95: 117-129.
- This study was conducted in the Atlantic lowlands of northeast Costa Rica, in timber concessions of poorly drained swamp forest.
- This study examined the effects of a controlled selective logging operation on forest structure.
- Harvesting was limited to trees of at least 70cm dbh, 10cm above the legal limit in Costa Rica.
- Extraction intensity averaged 6.3 trees/ha for 28ha and 45.8 m^3/ha for a 7 ha sub-sample.
- Felling, immediate residual mortality and skid trail construction reduced the basal area by 18.3%.
- Canopy cover averaged 91.4% in undisturbed plots and 73.4% in logged forest. The relationship between extraction intensity and post-logging canopy cover was linear.
- Skid trails covered 4% of the land surface. This number is slightly lower than in comparable studies, probably because much of the area surrounding the forest was pasture, so tree boles were skidded to landing outside the forest.
- Logging increased the median gap size from 46.6 m^2 to 83.5 m^2. Prior to logging 94% of the gap frequency and 60% of the total gap area was contained in gaps of less than 250 m^2. After logging, gaps with an area over 500 m^2 comprised only 17% of the gap frequency, but 78% of the total gap area.
- 17.6% of the residual stand was killed or damaged during logging (12.4% damaged, 5.2% killed).
- Severe damage (trunk snap or uprooting) usually did not occur to trees >50cm dbh
- Moderate damage types (canopy damage, bark removal) were relatively more frequent in size classes of >40cm dbh.
- When damage caused by the skid trail stabilisation (corduroy skid trails) is not counted, residual damage estimates decrease to about 12%.
- The absolute level of residual damage was very low compared to other tropical logging operations.
- Logging gaps with a low commercial value can comprise a substantial proportion of an improperly managed forest.
- The relative level of damage incurred during controlled selective logging did not appear to deviate substantially from uncontrolled logging operations.

Weidelt, H-J. 1996 Sustainable management of dipterocarp forests - opportunities and constraints. *In*: A. Schulte and D. Schöne (eds.). *Dipterocarp Forest Ecosystems: Towards Sustainable Management*. World Scientific Publishing Co. Pte. Ltd., Singapore. p.249-273.

- Volume increment, without deducting mortality, on an area of primary forest may range from 1- 5 m^3/ha/year.
- The absolute minimum logging cycle in dipterocarps is 35-40 years.
- The minimum felling diameter should be 50 cm, since dipterocarps generally reach fruiting age at dbh 35-40 cm.
- With directional felling techniques on average about 200 m^2/tree felled is damaged; so if 15 trees/ha are removed 30% of the area would have felling damage.
- In addition about 30% of the area sustains skidding damage.
- Imperative that logging damage is minimized to both the soil and the residuals.

Weidelt, H.J. 1989 Die nachhaltige Bewirtschaftung des tropischen Feuchtwaldes- Moeglichkeiten und Grenzen. *Forstarchiv* 60: 100-108.

- For Eastern Kalimantan a harvesting intensity of 35 to 105 m^3/ha with a 35 year cutting cycle appears to be sustainable (equal to 1-3 m^3/ha annual harvest).
- Silvicultural treatment can result in growth rates of 10 to 15m^3/ha.
- Studies on the Philippines indicate that a harvest of 50% of the basal area results in damages to 25% of the residual stand.

Wellhofer, S. 2002 *Environmentally sound forest harvesting in Brazil. Assessment of regeneration and environmental impacts four years after harvesting. Forest harvesting Case Study 19*. Food and Agricultural Organization, Rome.

- This study is a follow-up to a previous study in this series (Winkler 1997). Both studies were undertaken in a managed natural forest near Itacoatiara, in the Amazon region of Brazil. The two studies were conducted in collaboration with precious Woods Amazon (PWA).
- The purpose of this re-examination was to assess the condition of the forest four years after logging had been completed. For this purpose, assessments were undertaken of regeneration within felling gaps and on skid trails, water infiltration rates on skid trails, the current status of potential crop trees and the condition of residual trees of commercial species.
- Two plots, one treated with “conventional” logging techniques and the other with “environmentally sound” harvesting system were examined.
- Regeneration of seedlings, saplings and poles of both commercial and non-commercial tree species was generally satisfactory and appeared adequate to permit full recovery of the forest ecosystem over time. In addition, there was no significant difference in the numbers or sizes of tree regeneration, or in the numbers of tree species regenerating, between the two treatment areas.
- Regeneration on skid trail ruts was significantly less when compared to the less deeply disturbed side strips or centre strips on skid trails. There was no significant difference between regeneration in skid trails in the two treatment areas.
- There was no significant difference in water infiltration rates on skid trails between the two treatments.

Wells, C.H. 2002 Forest harvesting roads: meeting operational, social and environmental needs with efficiency and economy. *In* Enters, T.; P. Durst; G. Applegate; P. Kho & G. Man (eds.) *Applying reduced impact logging to advance sustainable forest management*. International Conference Proceedings, Kuching, Malaysia.

- The planning and construction of forest harvesting roads is a major and expensive operation that is critical to the orderly flow of logs.
- Codes of practice have aimed at setting basic standards to reduce the adverse effects of forest road alignment whilst still meeting operational and other needs.
- Such new standards are often opposed by the timber industry as being impractical and uneconomic.
- Experience in code development in the Asia-Pacific region indicates that proper road construction, sound environmental management, beneficial social outcomes and operational economics need not necessarily conflict.
- It may be necessary to collate, publish and disseminate road construction and management information.
- Training for roading supervisors, forest supervisors, forest officers and operators.

White, L.J.T. 1994 The effects of commercial mechanized selective logging on a transect in lowland rainforest in the Lopé Reserve, Gabon. *Journal of Tropical Ecology* 10(3): 313-322.

- Selective logging typically results in the destruction of 50% of all trees present before logging (Ewel and Conde 1976, Whitmore 1984, Johns 1992).

- In 1988 it was estimated that 46% of Gabon's forest had been selectively logged at least once, and each year about 2500 km^2 is logged; 60% of which has not previously been logged. Concession in the Lopé Reserve studied: logging intensity 1-2 trees/ha using conventional logging with chain saw felling and crawler tractor extraction (traditional logging in Gabon). Only recently has logging begun to diversify in Gabon with more species being extracted.
- Minimum legal felling diameter 70 cm dbh for commercial exploitation.
- For trees having a dbh >=70 cm (sample area 11.25 ha):
  - of the 175 trees (dbh >=70 cm) 30 trees died during logging and one died a year later, having a total basal area of 27.6 m^2 (17.7% of stems and 20.6% of basal area)(26 felled and 5 killed during operations)
  - 26 trees were felled, of which 23 were extracted (2 trees/ha extracted)
  - of the three trees not extracted, one was hollow and the other two were missed during extraction (=7.7% of felled trees)
  - road construction killed two trees and three were killed by falling trees during felling
  - few individuals were otherwise damaged during logging: three had partial crown loss and one lost bark when hit by a felled tree
- For trees having a dbh >= 10 cm (sample area 1.25 ha):
  - 505 trees measured and 6 lianas
  - basal area before logging 39.41 m^2/ha (408.8 stems/ha) and after logging 34.31 m^2/ha (364.8 stems/ha)
  - during logging 55 (10.8%) stems were lost, mostly due to incidental damage
  - three trees were cut and extracted (BA=3.7 m^2)
  - over half the trees lost were killed by falling trees (n=29, BA=1.3 m^2)
  - skidder damage killed 16 trees (BA=0.4 m^2)
  - seven trees were killed due to skid trails and roads (BA=1.0 m^2)
  - a further 12 trees (2.4%) sustained damaged but were still surviving after one year
- Canopy cover between 2-10 m was initially 58.2% and was reduced to 48.2% after logging.
- Overall canopy cover was 93.4% and was decreased to 83.2% after logging.
- 1.4% of surface area covered by a major road, 5.0% covered by secondary extraction roads (6.4% of area bare and compacted).
- 5.0% of surface area had skidder trails and 16.9% was covered by crowns of fallen trees.
- 71.7% of area was not physically altered during logging.
- Extraction rates and damage levels in other parts of central Africa are similarly low due to the low logging intensity.
- Adjacent area logged in 1986 roads covered 1.6% of site, skidder trails and secondary extraction roads made up 7.5% of site, and 51.2% of canopy suffered some disturbance.
- Adjacent area logged 10-15 years prior roads accounted for 1.8% of area and skidder and secondary extraction trails 7.2% of area.

Whitman, A.A., Brokaw, N.V.L & Hagan, J.M. 1997 Forest damage caused by selection logging of mahogany (*Swietenia macrophyllo*) in northern Belize. *Forest Ecology and Management* 92: 87-96.

- The study area was located near Hill Bank in northern Belize.
- The stands on this site were logged 10 or more years ago and had an intact canopy; approximately 92.3 ha were included in this study.
- Logging affected 12.9% of the study area.
- Skid roads covered 3.8% and affected another 6.3% and thus accounted for 78% of the disturbed area.
- Logging gaps covered 2.28% and accounted for the remaining 22% of the disturbed area.
- Logging of large trees did not necessarily produce larger gaps than logging of small trees.
- At logging gaps, soil density was not significantly different between gap, gap edge and skidding area.
- Soil was twice as compacted on skid roads than in adjacent forest. Soil compaction was over 200% greater on roads where more than one tree had been skidded. Overall, the soil was significantly compacted on 3.8% of the study area.
- Overall only a small part of the residual stand, trees, and regeneration were damaged by this operation.
- Average number of damaged stems per logged tree:

Species category	Skid road (trees damaged per tree logged)		Treefall gap (trees damaged per tree logged)	Total (trees damaged per tree logged)
	On Road	Next to Road		
Commercial	6.3	17.0	1.8	25.1
Other	6.3	13.9	4.1	24.3
Total	12.6	30.9	5.9	49.4

- Because similar numbers of commercial and non-commercial species were damaged, loggers did not appear to make an effort to avoid damaging species of commercial value.
- Compared to other neotropical studies, the area disturbed per tree harvested was nearly twice as great as was found in other studies. This may be attributed to the low harvest intensity, because the major proportion of the damage was associated with skid trails.
- In this study, the harvest rate for mahogany far exceeded the regeneration and recruitment capacity of the forest.

Winkler, N. 2001 *Forest harvesting operations in a timber concession in Suriname. Forest Harvesting Case Study* 15. Food and Agriculture Organization of the United Nations, Rome.

- The study was carried out in tropical natural forest of Sandaun Province and on New Britain Island, both Papua New Guinea. Two timber permit holders, namely Vanimo Forest Products Pty Ltd. (VFP), holder of Timber Permit TP10-8, and Stettin Bay Lumber Company Ltd. (SBLC), holder of Timber Permit TP14-52, agreed to host this study on forest harvesting operations in Papua New Guinea.
- The study documents each phase of the forest harvesting system currently applied by the above-mentioned companies, and compares planning and implementation of harvesting operations in the field against relevant regulations as published in the *Papua New Guinea Logging Code of Practice*.
- Data on felling operations were collected through work and time studies at both study sites, whereas data on extraction could be collected only at the VFP site in Sandaun Province. As one part of a post harvest assessment of environmental impacts, a survey of skidtrails was carried out at the study site in Sandaun Province.
- Felling at both study sites was done with the companies' equipment by workers with limited knowledge of felling techniques. Fellers were hired in compliance with a requirement of the timber permit that members of the landowner clan must be given employment preference. On the extraction operations the skidding assistants were hired under similar conditions. Tractor operators, however, were permanent employees and who remain with the skidding crew even when the harvesting frontier moves to an area owned by another clan.
- The time required to fell a single tree was greater on Set-up M38/SBLC (21.48 min) than on Set-up BL14/VFP (17.37 min) although the average stem volume was almost the same, 5.9 m^3 and 5.8 m^3 respectively. Differences in site conditions were identified as the primary cause of the difference in felling productivity at the two study sites. For the same reason, total felling and bucking production rates differed on the two sites (13.92 m^3/h of workplace time at M38/SBLC versus 16.91 m^3/h of workplace time at BL14/VFP) in spite of similar log volumes. The measured production rates are typical of those reported in the literature for felling and bucking by untrained workers in tropical forest.
- Skidding time-study data were obtained for two sub-samples of logs on Set-up BL14/VFP. The average skidding time on Sub-Sample 1 was 16.28 min/log at a maximum skidding distance of about 500 m, compared to an average of 24.40 min/log on Sub-Sample 2 where the maximum skidding distance was 1,050 m and weather conditions were significantly more difficult. Average production rates for the two sub-samples were 20.51 m^3/h of workplace time on Sub-Sample 1 and 13.28 m^3/h of workplace time on Sub-Sample 2.
- Investigation of timber losses revealed a significant potential for improvement, mainly in the felling operation, which accounted for about 90% of the total timber loss at study site BL14/VFP due to undiscovered decay prior to felling and stems split during felling. Total timber losses amounted to about 8.2% at the study site, or 1.57 m^3/ha. This is a typical level of forest residues according to a survey of the literature on harvesting in tropical forests.
- The forest area occupied by skidtrails amounted to only about 5% due to the hilly to mountainous terrain conditions in Set-up BL14/VFP. The machine operator had to make use of favourable terrain features such as ridges, and skidding of logs to the landing was generally carried out by retracing the path used to arrive at the felling site. However, the most striking fact noted during the skidding study was that only about 8% of primary skidtrails were planned, marked in the field, and approved through acceptance of the Set-up Plan by the Forest Authority's project supervisor. The remaining primary skidtrails were created in an ad-hoc way during the skidding operation.
- In the project areas visited for this study, forest harvesting clearly has a significant impact on the social and economic lives of the local people. It is currently the basis for nearly all economic development in the project areas, and thus influences the changes that are underway in local lifestyles. Such changes occur as people in remote areas become exposed to towns by the road networks developed to support forest harvesting, and the money earned through employment and payment of timber royalties permits them to purchase goods rather than relying on the traditional subsistence economy.
- The results of this case-study show that, although major steps are already being taken to foster environmentally sound forest harvesting through the introduction of the "Planning, Monitoring and Control Procedures for Natural Forest Logging Operations" under Papua New Guinea's Timber Permit system, and by implementing the PNG Logging Code of Practice, much remains to be done.

Winkler, N. & Nobauer, M. 2001 *Forest harvesting practice in a timber concession in Suriname. Forest Harvesting Case Study* 16. Food and Agriculture Organization of the United Nations, Rome.

- The study was carried out in a tropical natural forest of the Guyana Shield in the Forest Belt of Suriname close to Kabo, district of Para. One of the numerous small concession holders serving the local timber market was identified and proved willing to host this study, which required the application of "planned" harvesting on the co-operator's timber concession, number 387. The objective was to provide a comprehensive analysis of planned harvesting as an alternative to the conventional way of logging as usually carried out in Suriname.
- The study documents each phase of the conventional logging system, which is used almost exclusively in Suriname's small timber concessions and was applied on one sample plot at the study site. The productivity and environmental impacts associated with this system are compared with those of planned harvesting as applied on the other sample plot in Concession 387.
- Data on the two harvesting operations were collected under almost identical conditions. Work and time studies on harvesting activities in both systems, and post-harvest assessments of environmental impacts, were carried out in the adjacent sample plots at the study site.
- Felling in the conventional system was done by unskilled workers hired by the concessionaire and using the concessionaire's equipment. The same chainsaw operator was employed for felling in planned harvesting, but this time guided by the team leader of the inventory crew using the tree location map for the sample plot.
- For the timber extraction phase, the skidders and skidding crew of a logging contractor employed by the concessionaire were used in both systems. In planned harvesting, however, the skidding crew was guided by the team leader of the inventory crew using the tree location map.
- The average time required to fell a single tree was greater in the conventional logging system (8.67 min) than in planned harvesting (7.92 min) due to the time spent by the chainsaw operator (almost 10% of total time) searching for harvestable trees under the conventional system. Expressed in terms of volume recovered, felling productivity averaged 12.74 m^3/h of workplace time under planned logging as compared to only 9.25 m^3/h of workplace time under conventional logging.
- Skidding time for a single log under the conventional system, due to the time spent by the skidder operator searching for logs (again about 10% of total time), was significantly greater (23.87 min) than under planned harvesting (17.83 min). A similar result was found when comparing the productivity of the two harvesting systems with similar average log volumes per tree extracted. For skidding under planned harvesting, productivity averaged 8.15 m^3/h of workplace time, whereas skidding productivity under conventional logging averaged only 5.91 m^3/h of workplace time.
- If the labour cost per cubic metre of logs delivered to the landing under conventional logging is assigned an index value of 100%, then the comparable cost under planned harvesting would amount to only 77.5%, despite the additional labour cost required for pre-harvest inventory under planned harvesting. The substantially higher felling and skidding productivity under planned harvesting not only offsets the additional cost of the pre-harvest inventory but reduces the overall labour cost by more than 20%.
- Investigation of timber losses revealed considerable potential for improvement. Timber wastage ranged between 11.7% and 15.7% on the sample plots. In applying planned harvesting, timber losses related to missed trees could be avoided, which, by contrast, amounted to about 5% under the conventional system. However, the main timber losses observed during the study resulted from improper felling techniques.
- The superiority of planned forest harvesting over the conventional logging system is also underscored by the assessment of environmental impacts for both systems.
- Since the estimate of damage to residual trees was restricted to principal tree species (about 15 species), the percentages of residual trees found damaged on both sample plots were extremely low: 5.5% for conventional logging and 2.5% for planned harvesting. However, for the latter no damage was registered during skidding operations, whereas skidding damage was observed on the conventional logging operation.
- For the planned harvesting system an average of about 5.4% of the area harvested was affected by primary skidtrails, whereas in conventional logging the corresponding value more than twice as high-12.4%. In addition, conventional logging utilized secondary skidtrails, thus disturbing an additional area of soil which is not included in this figure.
- Canopy opening by tree felling ranged from 6.5% to 7.7% of the area for the two sample plots. Through directional felling, gap size could theoretically be controlled. However, chainsaw operators capable of applying directional felling techniques were not available during the time of this study. This highlights an important training need if logging practices are to be improved in the future.
- Perhaps the most important finding of this study is that planned timber harvesting can reduce costs significantly by comparison with conventional logging, in contrast to the strongly held belief that "reduced-impact" logging must necessarily cost more than "high-impact" logging. The results of this study suggest a labour-cost advantage of more than 20% for planned harvesting as compared to

conventional logging. This result is of course specific to the conditions under which this study was conducted and cannot easily be generalized. In particular, the relative wages of operators, assistants and members of the inventory crew, as well as conditions of timber, climate, and topography, should be considered carefully when comparing cost estimates for the two systems considered in this report with those for other countries or even other areas within Suriname.

Winkler, N. 1997 *Report of a case study on "environmentally sound forest harvesting": testing the applicability of the FAO Model Code in the Amazon in Brazil*. Food and Agriculture Organization of the United Nations, Rome, Draft Report. 59pp.

- Forest management plan is based on techniques developed by the INPA (Instituto Nacional de Pesquisa no Amazonas) and the CELOS Management System (Suriname, Agriculture University of Wageningen, Netherlands).
- The general concept of sustainable management in the project comprises of the following measures:
    - selective harvesting of 65 tree species of commercial interest
    - selective harvesting of approximately 35-40 m^3/ha (about a half of the average harvestable volume of commercial species per hectare found for the entire F2M forest area)
    - selective harvesting of mature trees with a dbh of >50 cm
    - low impact extraction operations to minimize damage to residual stands
    - application of silvicultural treatments in order to stimulate tree growth of commercial tree species
    - harvesting cycle of 25 years
    - monitoring system of permanent sample plots for growth and yield assessment and evaluation of damage to the remaining stand as well as for research purposes
- Terrain is fairly flat.
- Preharvest cruise to map locations of all commercial trees >50 cm dbh, as well as potential crop trees >20 cm dbh.
- There is a high variability in harvestable volume per hectare in primary forest; therefore, particular interest must be paid to reliability of data provided by a general inventory.
- The results of the commercial inventory also underline the importance of a comprehensive preharvest survey for each cutting unit comprising technical, topographic, economic and ecological factors, since it is considered as the most import tool in reducing logging waste (Panzer 1991).
- Operational cruising of the area is done two years prior to harvesting, each cutting unit is mapped individually, showing boundaries and all features that may influence the harvesting operations (water courses, swampy areas or other problems sites) on a 1:2000 scale map. Also, the locations of all potential crop trees are indicated on the map. At this time climbers are also cut.
- All information about each harvestable tree is recorded in the field and then fed into a computer for processing - trees are selected based on an minimum economic threshold (i.e., min. volume required), maturity of trees (oldest first) considering silvicultural guidelines for the management plan, as well as actual market acceptance of certain tree species.
- A computer generate map showing the location of potential crop trees is evaluated by a planner, the skid trail is located to maximize efficiency and minimize impact area.
- Spacing distance between skid trails planned at 100 m.
- If a selected trees is found to be rotten or will cause too much damage when felled, another crop tree is selected from close by, and the location of the rejected tree and reasons why indication on the map.
- All felled trees are marked on the map and numbers are attached to each log and recorded on data sheets to ensure no timber is lost; this data is entered into the computer and updated maps are given to the pre-concentration crew leader.
- Bunching occurs 2-weeks after felling and is done by winching the logs to the skid trails; some logs may be bucked due to weight and new numbers are given to each new log and recorded.
- Skidding occurs 2-weeks after bunching and the crew leader is given an updated map of the bunched logs at the sides of the skid trails.
- Skid trails and landing are considered to be permanent (i.e., used in subsequent entries into the stand).
- Work studies showed that felling operation productivity did not decrease with the planned changes from traditional logging (i.e., direction felling, proper felling technique to minimize damage to residuals and the tree itself, proper bucking to grading rules).
- Planned storage time for softwoods is 1 month and 2 months for all other species (considered to be no risk of quality loss due to insect of fungal attack, drying, checking).
- Traditional logging system used in the Amazon region in Brazil can be described as insufficiently planned, haphazard timber harvesting without any considerations concerning future crop and forest sustainability in general. Improper felling technique, which causes safety problems, timber loss as well as poor post harvest condition of the forest, and inefficient extraction due to lack of information about

terrain conditions, tree location and pre-planned skid trail location are further characteristics of the traditional logging system.

- In the traditional logging the operations are usually carried out in a chaotic way, e.g., a D6 crawler tractor or skidders go inside the stands without any plan searching for logs. The skidder operator drives to each log due to the lack of designated skid trails. There are remarkable losses of utilizable volume caused by forgotten, not extracted felled trees.
- Estimated felling production rates (time is workplace time excluding meals):

Method cutting unit	Number of trees harvested	Average m^3 per tree harvested	Average time required per tree harvested, min.	Productivity, m^3/h
Environmentally sound forest harvesting system B/G09	50	7.17	21.50	20.02
Traditional timber harvesting system B/F09	45	5.88	18.67	18.90

- Estimated extraction production rates (time is workplace time excluding meals):

Method cutting unit	Number of observations	Average volume per load, m^3	Average cycle time per load, min	Productivity, m^3/h
Environmentally sound forest harvesting system B/G09				
- pre-concentration	75	4.86	9.27	31.44
- kidding	79	4.72	4.27	66.37
Traditional timber harvesting system B/F09	43	4.73	10.35	27.43

- Estimated costs of harvesting. This is not a comparison of removal of the same volume from the study areas (from the ESFHS the volume removed was 86.7 m^3, while for TTHS it was 257.8 m^3):

Activities	Environmentally sound forest harvesting system B/G09				Traditional timber harvesting system B/F09	
	Actual		Planned			
	Productivity, m^3/h	Production cost, %	Productivity, m^3/h	Production cost, %	Productivity, m^3/h	Production cost, %
Commercial inventory		19.5		19.5	18.90	30.0
Forest road		30.0		30.0	27.43	7.7
Road maintenance		7.5		7.5		62.3
Felling	20.02	11.0	20.02	8.3		
Pre-concentration	31.44	32.7	31.44	29.8		
Skidding	66.37	11.6	66.37	11.6		
Total		112.3		106.8		100.0

- Unless the forest is left in a condition that will permit the attainment of a desired future condition, sustainability cannot be assured (FAO 1996). Therefore, post-harvesting assessments are an essential requirement of sustainable forest management since they provide feedback about the quality of the harvesting operations.
- The tables on logging damage in the report do not make sense - cannot understand what is being presented, because cannot compare removing 87 m^3 vs. 258 m^3 from similar (2.25 ha) sized areas (38.5 m^3/ha vs. 114.6 m^3/ha).
- However, the conclusion is made that severe damage to potential crop trees was about two times higher in the traditional logging area (71.7% of PCT undamaged in RIL, while 47.6% of PCT undamaged in traditional).
- Average gap opening 124.7 m^3, while Verissimo *et al.* (1992) found gap openings of 150-300 m^2 for natural tree falls.
- In the RIL the skid trails were 3.5 m wide, 1200 m in length and covered 4200 m^2 (18.7%).
- Traditional skid trails 4.98 m wide, 2646 m in length and covered 13177 m^2 (58.6%).

- Average area used for forest infrastructure per cutting unit:

	Environmental sound forest harvesting system B/B09			Tradition logging system B/F09		
	Coverage		Area	Coverage		Area
	m^2	m/ha	affected, %	m^2	m/ha	affected, %
Roads	625	12.5	0.63	625	12.5	0.63
Skid trails - primary - secondary	3500	100.0	3.50	13177	264.6	13.18
Landing	400		0.40	625		0.63
Total	4525		4.53			14.4

- In the study there were no trees lost since in both cases the logs were marked and numbered.
- There was a difference in felling and bucking losses (RIL = 3.9% and Traditional=8.5% of utilizable stem volume).

Wippel. B., Grulke, M., Becker, M. & Huss, J. 1997 Aussichten der Bewirtschaftung degradierter subtropischer Naturwaelder- Ergebnisse waldbaulicher und sozio-oekonomischer Forschung in Paraguay. *Forstarchiv* 68: 251-256.

- Expenditures and return on initial investments, Eastern Paraguay case study:

	Expenditures (US$/ha)	Return (US$/ha)
Large scale planning	0.96	
Construction of skid trails	140.77	
Designation of trees for harvest	19.28	
Stand tending and harvesting activities	436.29	
Stand regeneration	17.83	
Log yard, log sales	53.99	532.71
Subtotal	669.14	532.71
Total	136.43	

- Even without consideration of interest rates, depreciation and overhead administrative costs the initial treatment of degraded forests produces a deficit of US$ 136/ha.
- When forests are clear-felled only 10% of the timber volume is used as commercial timber or fuelwood (Bozzano and Weik, 1992).

Woods, P. 1989 Effects of logging, drought and fire on structure and composition of tropical forests in Sabah, Malaysia. *Biotropica* 21(4): 290-298.

- Increase in fires is due to forests becoming more prone to fire after disturbance by logging, which result in an accumulation of logging debris and opening up of the canopy.
- Of the 1 million ha burnt in Sabah in 1983, 85% had been logged over.
- Of the estimated 3.5 million ha of tropical forest burnt in Kalimantan, 77% had been logged over.
- In addition to more fires, tree mortality in burned logged over forest is higher than in unlogged forest (38-94% vs. 19-71%).
- Canopy loss is more severe in logged over areas and the ground cover was dominated by grasses or woody creepers, where in unlogged areas canopy loss was less severe and there was a low density of grasses.

- Logging mortality (includes trees extracted) and fire/drought mortality in the study plots by diameter classes (standard deviations in brackets):

DBH class, cm	Initial density, stems/ha	Logging mortality, %	Fire/drought mortality, %
Burnt plots (n=5)	252 (27)	30 (9)	72 (9)
10-20	102 (18)	21 (6)	55 (13)
20-30	45 (11)	12 (10)	53 (13)
30-40	29 (9)	8 (6)	49 (18)
40-50	20 (5)	10 (7)	49 (19)
50-60	35 (7)	31 (13)	38 (10)
60+			
Unburned plots (n=2)	264 (70)	25 (7)	24 (6)
10-20	102 (4)	19 (2)	17 (1)
20-30	34 (1)	22 (1)	20 (3)
30-40	22 (1)	20 (9)	28 (10)
40-50	16 (1)	6 (1)	12 (9)
50-60	42 (6)	32 (5)	25 (12)
60+			

Wyatt-Smith, J. & Foenander, E.C. 1962 Damage to regeneration as a result of logging. *Malaysian Forester* 25(1): 40-44.

- Area damaged by logging: roads and compartment boundary 9%, area covered by crowns 28%, area covered by boles 2%, = total 39%.
- Logged in 1959.

Wyatt-Smith, J. 1988 Letter to the Editor. *Forest Ecology and Management* 24(3): 219-223.

- Based on visits in 1987 to several SMS sites, as currently practiced, he does not hold out much hope of success in respect of sustained commercial volume production, except where Dryobalanops aromatica (kapur) predominates.
- Growth numbers used by Thang (1987) are based on minimal data (from 1978) which have been extrapolated from the eastern coast States and applied to the West Coast states which have a different climate and forest composition.
- Appears to be a lack of adequate silvicultural and ecological knowledge, management control, and long-term consideration of the future composition and rate of volume production of hill forest.
- Doubts that the 30-year SMS cycle will be achieved in practice, and states a case where one company has already reduced it to 25 years.
- Observations indicate that an economic cut of the best commercial species equitable to the logger appeared to carry the greatest weight in practice rather than ensuring sustained yield management of the valuable species.
- Logging damage and undue selection of logs extracted (in 1987) still appeared excessive.
- Quite clear that the operations in the concessions visited were not sustainable.
- An already built in 30% damage factor to intermediate-size trees at each cutting is unacceptably high, although unfortunately probably realistic.
- The SMS by design may yield a second cut of comparable volume to the first cut, however, it will contain a proportion of less-desirable commercial species (current standards). The major problem will be in the volume available from the third and subsequent cuts.

Yeom, F.B.C. 1984 Lesser-known tropical wood species: how bright is their future? *Unasylva* 36: 3-16.

- Domestic markets are less discriminating.
- Problems with increased use of LKS: difficulty in identification/inadequate data on physical and mechanical properties/incorrect marketing in wrong end-uses/irregular or inadequate supplies/poor grading.
- To what degree can there be extensive increases in the harvesting of LKS before unacceptable levels of environmental damage occur.
- At the end of 1980 it was estimated that the total growing stock in Asia forests was 31000 million m^3, of which more than 3000 million (1/10th) m^3 were of commercial importance in accordance with existing standards of utilization.
- If supplies prove scarce in one country because of resource depletion, a ban on log exports, or higher costs, there is always an alternative supply, at least in the short and medium term.
- When one can pick and choose in this way, there is naturally little or no interest in the LKS as far as the consuming countries are concerned.

- Get a problem in smooth processing (may need to have wood stored and sorted too much if there are more species in small quantities).
- But demand influences all - at end of last century only one species was used in north Queensland (Australia), by 1900 10 species used, by 1930 30 species used, during and after the war years 100 species used by the sawmills and plywood industries.
- Logging intensity in many tropical America countries 8.4 m^3/ha and African countries 13.5 m^3/ha.
- Logging intensity in Malaysia and the Philippines is extremely heavy at about 45 m^3/ha in Peninsular Malaysia, 75 m^3/ha in Sarawak and 90 m^3/ha in both Sabah and the Philippines.
- Marn and Jonkers (1982) - 53 m^3/ha (13 trees/ha) logging intensity in MDF in Sarawak.
- 50% of residual crop trees uprooted, broken or injured (Marn and Jonker 1982).
- Abdulhadi et al. (1981) found 60% of the residual stand undamaged with the extraction of 11 trees/ha.
- Studies in Sabah have shown only 34% of the residual trees undamaged.
- 2000-3000 larger tree species in the tropics.
- Soil damage through erosion and compaction is another serious logging impact that could impair forest productivity.
- Opening the canopy up too much with more intensive harvesting of LKS can result in extreme competition from weeds, bamboo, climbers, etc., which are costly to control.
- What is the threshold for logging? The review and discussions above suggest that it may be of the order of 50-90 m^3/ha, which is more or less the same logging intensity in Asia.
- Viewed with this broad management perspective, the current non-utilization of the LKS is perhaps a blessing in disguise in many Asian countries.
- However, in Latin America and Africa, where logging intensities are low, ecological problems arising from harvesting increased volumes of LKS are generally of less concern.
- Need to have end-use grouping of LKS to enable economical batch sizes for processing.
- Where logging intensity is low, LKS are a good potential source of wood.