GLOBAL FIBRE SUPPLY STUDY
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Literature Synthesis on Logging Impacts in Moist Tropical Forests

Reino E. Pulkki

Working Paper GFSS/WP/06

December 1997

Food
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FOREWORD

In late 1995, the FAO Forestry Department initiated the Global Fibre Supply Study (GFSS) with an outlook to the year 2050. The study was recommended by the FAO Advisory Committee on Pulp and Paper (now the Advisory Committee on Paper and Wood Products). The general objective of the study is to contribute reliable data, information, forecasts and analysis of industrial fibre sources in order to promote sustainable forest management.

The GFSS will include a compilation of the latest available inventory data, including recovered and non-wood fibre, focusing primarily on the sources of industrial fibre as raw material for the sawmilling, wood-based panels, and pulp and paper industries. It will also include a projection and analysis of future developments in fibre supply, based on explicit consideration of the major factors affecting supply.

The GFSS is unique among FAO studies in that special emphasis is placed on collection and compilation of fibre volume inventory and growth data for the developing regions - Africa, Asia-Pacific, and Latin America and the Caribbean. The study complements other FAO work, such as the Asia-Pacific Forestry Sector Outlook Study and the upcoming Forest Resources Assessment 2000. FAO is also updating its statistics on forest plantations and developing a method for estimating fibre volumes from non-forest areas in the tropical regions. Available data from these studies will be included in the GFSS.

The major products of the GFSS will include:

- A database accessible on-line through the Internet providing estimates of commercial wood volumes from natural, semi-natural and plantation forests;
- An on-line interactive fibre-supply model incorporating key determinants of supply;
- A statistical and descriptive report on the data and three fibre-supply scenarios which are based on factors deemed to be the most critical;
- A working paper describing in detail the methods for data compilation, gap filling, data validation, forecasting and definitions, survey forms and country list;
- A series of additional working papers on sustainable forest management, improved forest productivity from industrial forest plantations, fibre-supply modelling, recovered and non-wood fibre, and other topics; and
- An issue of *Unasylva*, FAO's quarterly journal on forestry and the forest industry, dedicated to the theme of global fibre supply.

This paper, solicited by the GFSS and prepared by Reino Pulkki, summarizes the literature on logging impacts in moist tropical forests. We sincerely hope that it contributes productively to the world-wide dialogue on sustainable forest management for fibre and other values.

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1. INTRODUCTION

Byron and Perez [1996] and Sayer *et al*. [1997] indicate that virtually all fibre for pulp and paper and reconstituted wood panels can be derived from plantations and heavily modified temperate forests. The non-coniferous tropical forests (NCTF) on the other hand will provide high-value wood, such as veneer logs and sawlogs, for niche markets. There is a general consensus though that management of natural tropical moist forests is preferable to plantations and that plantations should only be established in areas where the forest has already been cleared or devastated [Chim and On 1973, Jonkers and Schmidt 1984, Poore and Sayer 1987, Jabil 1993]. Plantations and natural forest management are complementary, with each supplying different products and being most applicable to different types of terrain and forest conditions [Schmidt 1987].

This Global Fibre Supply Strategy (GFSS) working paper summarizes a review of the literature on logging intensities, cycles and waste, and residual stand and site damage in NCTF. The purpose of the review is to provide background information for a component of the GFSS where the supply of non-coniferous veneer logs and sawlogs from tropical forests was modelled [Pulkki 1997]. Paramount in determining the available supply of wood from NCTF are the logging intensities and cutting cycles applied (definitions of more widely used terms in this paper are given in Appendix A). In turn, over the long run the logging intensities and cycles are greatly impacted by the extent of damage to residual trees and the site on each entry and the proper selection of trees for removal. The literature reviewed is summarized in tabular form by countries and regions in Appendix B. Appendix C contains the full summary of each report reviewed.

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 practised. 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." Dykstra and Heinrich [1996] outline RIL in detail.

RIL techniques are not difficult to implement and, once fully used on an 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 thus 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 contained in the GFSS database [Pulkki 1997].

3. INCREASING FELLING INTENSITY

3.1 LESSER-USED SPECIES

In many areas, species initially viewed as weeds have become valuable sources of raw material. For example, in Finland during the 1950-1960s, birch (*Betula pedula*) was thinned out in plantation cleaning work. Today, birch is a valuable raw material for high quality printing papers and a significant volume of birch is now imported into Finland (8.3 million m^3 in 1995) [Sevola 1996]. Similarly, aspen (*Populus tremuloides*) was considered a weed in Canada prior to 1980, but today aspen is a valuable source of fibre for hardwood kraft and OSB (oriented strand board) mills.

A similar development is occurring in the NCTF. Increased use of lesser used species is seen by many as a way to make the management of natural forests more viable economically since increasing the volume removed generates more revenue per hectare [Sarre 1995]. Also, Fickinger [1992] states that any form of utilization that relies on natural regeneration must be based on a wider range of species. Of the 19 country summaries given in ITTO [1997], 11 summaries make reference to initiatives to improve utilization of currently underutilized or lesser known species for veneer logs and sawlogs. Another four country summaries refer to increased reliance on plantations. Several country summaries also make reference to the need to reduce mill residues through improved mill technology and changes in quality standards.

Where logging intensities are low, the underutilized species are a good source of additional log volume [Yeom 1984]. However, increased logging intensity can lead to greater disturbance with each entry [Wagner and Cobbinah 1993] and thus lead to reduced yields in subsequent entries and unsustainable forest management (i.e. forest liquidation) [FAO 1989b]. Re-entry prior to the full logging cycle to harvest another species which becomes commercial must be prohibited [Jonsson and Lindgren 1990]. There is also a danger in placing too much reliance on the increased use of lesser used species, since it can provide an excuse for continued mismanagement and uncontrolled logging of NCTF [Bethel 1984]. Bruenig [1996] states that felled trees and not the forest need to be utilized better.

3.2 LOWER FELLING LIMITS

There is also a trend to reduce felling limits to increase logging intensity. This, however, can disrupt the regeneration potential of NCTF managed under polycyclic silvicultural systems [Thang 1986, d'Oliveira and Braz 1995, Reitbergen and Poore 1995]. According to Bruenig [1996], lowering felling limits to increase logging intensity must be avoided and, for example, should not be lower than 60 cm in dipterocarp forests. Maintaining sufficient canopy cover is also necessary to reduce erosion due to tropical downpours [Myers 1983], to maintain the forest as a fire-resistant ecosystem [Uhl and Buschbacher 1985, Woods 1989, Gerwing *et al*. 1996], and to control invasion of the site by climbers and lower value pioneer species [Neil 1984, Tuomela *et al*. 1996]. The minimum felling limit needs to be matched to the silvics of each species, and where information is not available to justify its lowering, it should be maintained at current levels (minimum diameter of 50-60 cm).

4. WOOD WASTE

4.1 IN-FOREST LOSSES

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 percent [Silitonga 1987, Bhargava and Kugan 1988, Gerwing *et al*.

1996, Muladi 1996, Scharpenberg 1997] to 50 percent [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 percent in Africa, 46 percent in Asia/Pacific, 56 percent in Latin America and the Caribbean, and 50 percent 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 percent of the tree was extracted; of the remaining volume 4.6 percent was stump, 5.2 percent buttress, 10.4 percent stem off-cuts and 26.3 percent 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 percent 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 percent of the logging waste he found. The estimated volume of waste due to felling and bucking losses is about 6.5-8.5 percent 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 percent 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 percent reduction in waste associated with felling a bucking, while Winkler [1997] found a 120 percent reduction. DeBonis [1986] also found that a 15-30 percent increase in wood volume at the mill could be realized through proper felling and bucking techniques. Cross-cutting training programmes have also shown that log values can be increased by 10-50 percent [Dykstra and Heinrich 1996].

4.2 OUT-OF-FOREST LOSSES

Wood volume losses or waste also occur at roadside landings, export ports, millyards and in manufacturing itself. For example, Kilkki [1992] found in a study in Papua New Guinea that 10-35 percent 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 percent, and typically averages no more than 30 percent. This is supported by Buenaflor and Karunatilleke [1992] who state that 70 percent 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 percent 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 percent to 57 percent. In other reports reviewed, the LRF reported varied from 45-55 percent [Silitonga 1987, Kilkki 1992, Verissimo *et al*. 1995, Muladi 1996]. When sawing large diameter tropical hardwood logs the LRF should be at least 50 percent [Uhl *et al*. 1997], and yields of 56-68 percent should generally be expected [Niedermaier 1984].

5. LOGGING DAMAGE

5.1 RESIDUAL STAND

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 B it is quite apparent that damage to the residual stand in conventional logging operations is excessive and the percent of residual trees damaged ranges from 33-70 percent in areas with higher (>30 m^3/ha) logging intensity [Nicholson 1958b, Fox 1968, Burgess 1971, Tinal and Palenewen 1978, Abdulhad *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 intensity (e.g. in Africa with removal of 1-2 trees/ha) residual stand damage generally ranges from 10-20 percent [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 to200 percent [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 intensity can be significantly increased and still result in less damage to residuals. For example, Buenaflor [1989] found 67 percent of residuals damaged in uncontrolled logging with 23 m^3/ha removed, while in a controlled logging area 22 percent 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 percent 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.

5.2 SITE

As with residual stand damage, site impacts in conventional logging of NCTF are excessive. In high logging intensity and uncontrolled logging areas, 30-75 percent of the area can be seriously 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]. However, typically in higher logging intensity areas (30-50 m^3/ha), 10-25 percent 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]. In lower logging intensity areas the soil disturbance is from 6 to 13 percent 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].

The implementation of RIL techniques results in less site impacts, and skid trails generally develop good regeneration and crown cover [ISTF 1995]. Winkler [1997] found that in conventionally logged areas 14.4 percent of the area was covered by roads, skid trails and landings, while in RIL areas only 4.5 percent of the area was impacted (>200 percent reduction). Marsh *et al*. [1996] found similar results, where in RIL logged areas 3.8 percent of the area was covered by skid trails, compared to 12 percent in adjacent conventionally logged areas. In a study by Moura-Costa [1987], 17 percent of a conventionally logged area was covered by roads, trails and landings, while only 6.2 percent was covered in the RIL area. Malvas [1987b] determined that, with optimally spaced and located roads, skid trails and landings a minimum of approximately 5 percent of the area would be impacted. Hendrison [1989] states that on average an efficient road and trail system should be limited to a maximum of 5-8 percent of the area.

6. 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 [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 practised in NCTF is non-sustainable and this is reflected in the GFSS database with considerable reductions in veneer log and sawlog 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 (Appendix B). 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/a). 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 more 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. It 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.

APPENDIX A: TERMINOLOGY

DBH (=dbh, dbhob)

Tree diameter at breast height, outside bark.

FELLING LIMIT (= cutting limit)

Felling limit refers to the minimum diameter at breast height (dbh) of a tree which may be extracted in logging operations. In selective and selection harvesting of non-coniferous tropical forests, felling limits generally vary between 45 and 110 cm depending on species and country.

LOGGING CYCLE (= cutting cycle, harvesting cycle, felling cycle):

Logging cycle refers to the time between successive cuts within a stand or compartment and is generally used in reference to selection or selective silvicultural systems. The optimum logging cycle ensures complete forest recovery and sufficient stem recruitment into the exploitable diameter classes [Dykstra *et al*. 1996]

LOGGING INTENSITY (= harvesting intensity, cutting intensity, felling intensity):

Logging intensity refers to the of volume per hectare of industrial wood extracted from the forest at each entry; the length of period between entries corresponds to the logging cycle.

RESIDUALS

The term **residual(s)** (residual trees, residual stand) refers to the trees/stand left standing after logging operations, e.g. after selection cutting or thinning. In most cases the objective is to ensure healthy trees, which are still increasing in size and/or value, are left. For this reason there must be minimal or preferably no logging damage to the residual trees. Increasingly, some standing dead trees are left to fulfil biodiversity objectives. In most cases, however, selective logging (= high-grading) occurs: "a type of exploitative cutting that removes only certain species (a) above a certain size, (b) of high value, known silvicultural requirements and/or sustainable yields being wholly or largely ignored or found impossible to fulfil" [Ford-Robertson 1971].

RESIDUES AND WASTEWOOD

According to Ford-Robertson [1971], **wastewood** is defined as "strictly those portions of a tree or log that could be profitably utilized but are not", while **refuse** is defined as "those portions of a tree or log whose removal from the forest or utilization at the mill cannot be justified economically". **Residue** is the combination of the above and refers to "wood left over from any conversion process, whether true refuse, true wastewood or destined for further conversion" [Ford-Robertson 1971]. Residue can refer to mill or logging residue. In many cases the residue of one mill is the raw material for another, e.g. sawmill chips feeding a pulpmill.

Mill residue refers to any wood fibre (both wastewood or refuse) not utilized by the conversion process at a mill, be it a sawmill, veneer mill, plywood mill, pulpmill, etc.

Logging residue refers to any wood fibre (both wastewood or refuse) lying on the ground as a direct result of the logging operations. The residues may range from portions of trees to entire trees run-over and broken by the logging equipment and left. Logging residues can be found directly in the stump area, along the skid trails to the landings and at roadside landings.

Forest residues, on the other hand, are all wood residues on the forest floor resulting from natural causes and logging operations. For example, in a large windthrow area the wood on the ground would be classed as forest residues, irrespective of whether salvage operations have occurred or not.

APPENDIX B: TABULAR SUMMARIES

REFERENCES TO AFRICA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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
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 m3/ha, of which 61 m3/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
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				Nwoboshi 1987

REFERENCES TO INDIVIDUAL COUNTRIES IN AFRICA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 1980
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 1994
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 1992
Madagascar		- logging intensity 10 m^3/ha			Ganzhorn *et al*. 1990
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 1993

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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) - 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)	- 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 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	Scharpenberg 1997
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 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	- logging intensity 1-2 trees/ha using conventional logging with chain saw felling and crawler tractor extraction - 70 cm minimum legal felling diameter for commercial exploitation - in 11.25 ha study area logging intensity 2 trees/ha	- 26 trees >70 cm dbh felled, 23 extracted (2 missed and 1 was hollow), plus 5 killed during operations - of the 175 stems dbh >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 - overall canopy cover was 93.4% and was decreased to 83.2% after logging	- 2 trees >70 cm dbh killed during road construction - 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 by logging - 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	White 1994

REFERENCES TO BRAZIL

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 and Johns 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 and Uhl 1995
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 that the growing stock is maintained at a desirable level	- logging intensity 20 m^3/ha	- with RIL the number of damaged trees (dbh >10 cm) per tree logged was 5.3 (or 0.27 m^3 damaged per m^3 extracted)	- with RIL maximum canopy opening was 15% - 22.5 m/ha of road built (5 m wide), 60 m/ha of skid trails	d'Oliveira and Braz 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)	- in three previously logged sites 6.6 m^3/ha of usable timber was felled but never skidded (represents 1 tree/ha) - 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) - 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 feller and directional felling similar losses were 0.11 m^3/tree or 1.7 m^3/ha less wastage - 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		Gerwing *et al*. 1996

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Brazil	- study of RIL with vine cutting 18 months prior to logging - directional felling made 85% of the 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		- improved skidding operations resulted in less forest damage, less timber extraction time and lower extraction cost, than in the conventionally logger area	- RIL looked much better, skid trails had good regeneration and canopy cover, the canopy openings looked very similar to natural tree fall gaps	ISTF 1995
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	- considerable damage at the time due to careless siting of skid roads - forest had regrown over 11 years to a basal area of 15 m^2/ha		Johns 1991
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

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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 sawmillers 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 m2/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 and Anderson 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 sawlogs, and 4.1 m^3/ha of non- commercial species)			Malinovski 1996
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 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

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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 quicly 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 and Buschbacher 1985
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 m3/ha (4-8 trees/ha or 1-2% of all tree stems >10 cm dbh) of 30-60 species - first study area 52 m3/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)	- 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 preharvested stands)	- 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)	Uhl and Viera 1989
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 and Kauffman 1990

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Brazil, Amazon	- Tailandia - 2-3 m^3 of logs required to produce 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	- average 2 trees/ha (16 m^3/ha) were extracted in three 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	- 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 - 0.37 trees/ha were not extracted due to defect (usually rot) - loss of canopy cover averaged 8.1% - 1.2 m^3 of wood was destroyed for each m^3 harvested	- on average 56 m of logging road were constructed 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	Uhl *et al*. 1991
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 - 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 - 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%		Uhl *et al*. 1997

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Brazil, Amazon	- Paragominas - 238 sawmills studied with a lumber yield of 47% (2.13 m^3 roundwood per 1 m^3 of sawnwood) - 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	- 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)	- 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	Verissimo *et al*. 1992
Brazil, Amazon	- mahogany extraction - one band sawmill will on average produce 4500 m^3/a of mahogany sawnwood from 9900 m^3 of roundwood (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) - 31 trees (dbh>10 cm) were severely damaged for each mahogany tree extracted - 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	Verissimo *et al*. 1995
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 - average gap opening 124.7 m^2 - in RIL, felling and bucking losses were 3.9% of utilizable stem volume, while in traditional logging it was 8.5%	- 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	Winkler 1997

GENERAL REFERENCES

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 1984
General	- tropical moist forest	- a felling intensity of 5-8 trees/ha is considered to be sustainable for most types of tropical forests			Boerboom and Wiersum 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 and Lugo 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, overlogging and underutilization persist in tropical forests and elsewhere	- felled trees not the forest need to be utilized better - 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	- overlogging 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 1996
General			- 15-35% of all residual trees damaged in polycyclic systems - 40-60% of all residual trees damaged in monocyclic systems		Bruijnzeel 1992

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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 and Perez 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 1976
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 roundwood		- 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 1992
General	- sufficient information exists to permit sustainable harvesting operations in virtually any area of tropical forest worldwide				Dykstra and Heinrich 1992
General			- experience in training programmes to improve cross-cutting skills suggests that improved utilization of 20% or more and increased log values of 10-50% can be attained		Dykstra and Heinrich 1996

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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 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	- 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 firme forests yield 3-5 trees/ha (10-15 m3/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			Johns 1992

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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 manoeuvering, 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 and Lindgren 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 and Cedergren 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 1992
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
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 overall average 37 m^3/ha/entry	- common to find 40-70% of the advance growth destroyed in the harvesting process, leaving only 12-33 stems/ha for the next cut - very heavy damage (70-100%) can be expected when basal area extracted rises about 12 m^2/ha		Masson 1983

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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 and Jonkers 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 1983
General	- product yields that can be generally expected are: =sawnwood 56-68% = plywood 50% = waferboard 75-80% = strandboard 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 1984
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 offcuts, 26.3% in crown with diameter >20 cm - of stem between crown and stump 77.4% extracted as log		Noack 1995

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General	- one of the many paradoxes of tropical forestry over the past 30 years is that the rise in public interest has been parallelled 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 money in management for future production and often led to such investments being lost	- 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 noncommercial 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 and Synnott 1992
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 and Sayer 1987
General	- commercially exploited forests are important components of local, regional and global conservation and development strategies				Putz and Viana 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		- in highlead 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 highlead setting is probably due to working on steep terrain (>40%), where felled trees tend to roll more and thus cause more damage to residuals	- 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	Rapera 1978

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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 and Poore 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 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 - 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				Sarre 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

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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 and Byron 1996
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

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 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	- if residual crop trees are 10 cm dbh on average a minimum logging cycle of 40 years is required to get average 50 cm 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 m3/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 m3/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			Schmidt 1987
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 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 1984

REFERENCES TO GHANA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
Ghana			- harvesting >3.5 m^2/ha of basal area will exceed the forest's ability to regenerate		Agyeman *et al*. 1995a
Ghana	- Bura Forest Reserve	- logging intensity 2.3 trees/ha	- gap opening per felled tree ranged from 350 to 1800 m2	- felling 2.6 trees/ha resulted in 13% logging disturbance - canopy openings accounted for 50% of the disturbance, skid trails 38% and haul roads 12%	Agyeman *et al*. 1995b
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 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 1997
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 m3/ha/a	- minimum felling limit is 70 cm dbh - cutting cycle has just recently been increased from 25 to 40 years			Wagner and Cobbinah 1993

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
	- 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				

REFERENCES TO INDONESIA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
Indonesia, East Kalimantan	- lowland dipterocarp (Lempake)	- 11 trees/ha (stumps 80-150 cm diameter)	- 41% residual stand damage		Abdulhad *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 and Sist 1997
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 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 and Heinrich 1990
Indonesia, West Kalimantan	- lowland rainforest	- harvest removed 43% of precut basal area or 62% of precut 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

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 - 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	- cutting cycle is 35 years and the minimum felling dbh is 50 cm - logging intensities at Narkata Rimba were 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%	- 75% of injuries caused by skidding and 25% by felling - higher residual stand damage results in higher mortality - residual stand damage increases as slope increases (at Narkata Rimba 9.4, 21.1 and 35.4% residual tree damage 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)		Elias 1996
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 sawlog 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 1978
Indonesia, East Kalimantan		- logging intensity 25 trees/ha		- 30% of ground surface covered with tractor paths	Kartawinata 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 and Setyarso 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 1996

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	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 m3/ha of all species with dbh >50 cm = a seasonal logger would extract 36 m3/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 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		- study 1 wood waste was 12% and 22% stemwood 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 minimum 30 cm diameter - study 3 found wastewood based on a clear bole basis to be 25.1% in Kalimantan and 21.9% in Sumatra - study 4 average wastewood was 19 m^3/ha (minimum 1.0 m length and 10 cm diameter inside bark) - wastewood in tropical rain forest is 24-26% of the extracted volume - if going down to a 30 cm diameter wastewood is 32-35% of the extracted volume - for mangrove forests wastewood is 9% and for teak forests 11%	- average road density of 15-20 m/ha is acceptable	Silitonga 1987

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 dbh class; 19 in 50-69.9 cm dbh class; 60 in >70 cm dbh class)	- 50.1% of residual trees had no damage (958 residual trees or 240 trees/ha left 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 - 41 (commercial species) trees/ha left after logging of which 13 trees/ha were dipterocarps		Tinal and Palenewen 1978
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

REFERENCES TO INDIVIDUAL COUNTRIES IN LATIN AMERICA AND THE CARIBBEAN

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
French Guiana	- average volume in area (>10 cm dbh) 350 m^3/ha and basal area 31 m^2/ha	- base treatment removes 33 m3/ha (2.6 m2/ha of BA)			Bariteau and Geoffroy 1989
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 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%		Cordero and Howard 1996
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		- sawyers receive no formal training in felling or bucking - with the use of proper felling and bucking technique a 15-30% increase in wood volume at the mill could be realized	- 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) - 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 - preplanned skid trails and directional felling can reduce the area covered by skid trails to 15% - by confining skidders to skid trails and using the winch more, skid trails could be reduced to 4% of area - if only advanced planning of skid trails and wet-weather shutdown were implemented, most of the current skidding damage coud be eliminated	DeBonis 1986

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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, 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	Gullison and Hardner 1993
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 m3	- 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		Hernández-Diaz and Delgado-Pacheco 1996
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	- 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 original stand 183 trees/ha were not felled or damaged		Inglis et *al*. 1997
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)			Mason 1996
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

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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)			Plonczak 1989
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 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 - cost of detailed inventory for CATIE (RIL) is US$27/ha		- loggers paid based on the volume removed, therefore they only take out the best and largest logs - 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		Quirós *et al*. 1997
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	- 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	- uncontrolled skidding is a major cause of damage to the ecosystem	ter Steege *et al*. 1996

REFERENCES TO MALAYSIA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
Malaysia		- increased from 24 m^3/ha(1971-78) to 45 m^3/ha (1979-90)			Abhluwalia and Karnasudirdja 1995
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 1978
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 and Putz 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 1995
Malaysia, Sabah	- logging residues were all pieces >2 m in length and >45 cm diameter		- on average logging waste amounted to 18.3% of the actual log production - 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 defects - total utilizable waste based on removed log volume was 27.7% - 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%		Bhargava and Kugan 1988

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
Malaysia, Peninsula	- hill dipterocarp forest		- 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)	- disturbance to 17.8% of soil area with tractor logging and minimum felling diameter of 60 cm	Borhan *et al*. 1987
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 1971
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 1978
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 1975
Malaysia			- greatest menace to advance growth is careless extraction rather than felling		Chai and Udarbe 1977
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 and On 1973

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 - 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 damage - of 42.5 potential dipterocarp residual crop trees/ha in the study area, only 14.3 trees/ha had little or no damage - also found that the higher the felling cut on the tree, the higher the losses to log shattering, splitting and torn bases		Fox 1968
Malaysia		- average logging intensities = Sabah 120 m^3/ha = Sarawak 90 m^3/ha = Peninsula 52 m^3/ha	- levels of damage of the forest are correspondingly high - in coupes logged during the late 1980s, tree losses during felling reached 62% under conventional tractor logging techniques, and 80% under overhead cable techniques		Grieser-Johns 1996
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 1987a
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, 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 1987b

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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	- 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
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 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				Jabil 1993
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 1988

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 and Heuveldop 1993
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 - 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	- 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 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	- in many cases half or more of the trees remaining after logging are damaged, some of them so badly 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 relogged forest often deteriorates into a state of unproductive weeds		Korsgaard 1985
Malaysia, Sarawak	- hill forests	- 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		- lack of planned skidways in the forest leads to the creation of numerous tractor paths for seeking logs	Lee 1982
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 and Grip 1990
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 1987a

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 1987b
Malaysia, Sabah	- dipterocarp forest - RIL and proper selection harvesting are essential elements of sustained management of tropical forests - after logging the area must be closed from further operations and skid trails rehabilitated	- in eastern Sabah the average log weighs 7-9 tons and 80-100 m^3/ha are extracted - RIL logging intensity 103 m3/ha (8.8 trees/ha) - conventional logging intensity 139 m^3/ha (13.6 trees/ha)	- RIL not only minimized all external environmental costs but also assures greatly improved future harvests with little or no need for further silvicultural treatments	- research plots demonstrated a 50% reduction in 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	Marsh *et al*. 1996
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 m3/ha			Mattsson-Marn 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	- with RIL overall damage to residuals reduced by 50%, skidding efficiency increased 36% and there was no cost increase with directional felling - 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		Mattsson-Marn and Jonkers 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

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 m3/ha)	- average logging intensity 69 m^3/ha - 50-83 m^3/ha possible on a 40-year logging cycle	- 40 years after logging (highlead logging) the average dipterocarp volume per hectare is half of that of adjacent unlogged forest	- between 20-40% soil disturbance with heavy equipment	Meijer 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 (% 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 - 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		Miller 1981
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 - growth and yield studies in Sabah and Sarawak have shown similar results	- current average logging intensity in hill forests is 40-45 m^3/ha			Mok 1992
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 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	- 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 logging	- in RIL area 29% of residual trees damaged - in conventional logging area 56% of residuals damaged	- 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 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%	Moura- Costa 1997
Malaysia, Sabah				- soil disturbance by tractor trails bare of regeneration averages 14% of the logging area	Nicholson 1958a

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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	- 53% of residual trees were damaged (fallen or broken off trees 30%, bark damage 11%. crown damage 4%, minor damage 8%) - 35% of the undamaged trees had good form and 12% had poor form - amount of damage to residuals increases with logging intensity		Nicholson 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 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	Nicholson 1965
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 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%	Nik and Harding 1993
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 and Hoe 1996

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 RIL area	- 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	- 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 logged areas 87% were exposed - RIL resulted in 50% less damage to soil and residual trees	Pinard *et al*. 1995
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	- no correlation found in study between volume removed and damage to residuals - 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		Pinard and Putz 1996
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	- 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, Sabah	- clearfelling 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 clearfelled area	Sim and Nykvist 1991
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 1986

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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	- damage levels by dbh class in SMS were >60 cm=20%, 45-60 cm=30%, 30-45 cm dbh=40%, 15-30 cm=50% - 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 - important to curtail logging damage to the residual stand to not more than 30% of the intermediate-sized trees (30-45 cm dbh)		Thang 1987 (same data presented in FAO 1989b)
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 - in addition to more fires, tree mortality in burned logged-over forest is higher than in unlogged forest (38 to 94% vs 19-71%)				Woods 1989
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 and Foenander 1962
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 *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	- the SMS by design may yield a second cut of comparable volume to the first; however, it will contain a proportion of less-desirable commercial species (current standards) - the major problem will be in the volume available in the third and subsequent cuts	- 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 - 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		Wyatt-Smith 1988

REFERENCES TO NIGERIA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 1994
Nigeria			- 12.2% waste	- extraction in the concession was heavily mechanized and productive, but caused considerable disturbance to the surrounding areas	Agom and Ogar 1994
Nigeria	- Nigerian tropical shelterwood 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 m3/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, 1978
Nigeria	- moist tropical forest - study of 5 high forest reserves show mean annual increments of about 5.0 m^3/ha/a +/- 1.0 m3 (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 1992
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	- 17.7% of residual trees damaged - 51 trees were knocked over (mostly in the >30 cm girth classes)	- 8% of area bared for manual and lorry method compared to 30% for mechanized operations	Ola-Adams 1987

REFERENCES TO PAPUA NEW GUINEA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 m3/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 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 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 - corresponding dbh increment in undisturbed site was 0.39 and 0.42 cm/a	- 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 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 - destruction of advance growth will increase the logging cycle of A. cunninghamii by 100 years due to the slow initial growth		Enright 1978

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 - 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	- the greater than 30% of area covered by landings, roads and skid trails could be reduced to 15%	FAO 1991
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	- 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 - 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% - 10-35% of the export volume was left at the harbour as not fulfilling export grade rules		Kilkki 1992
Papua New Guinea	- clearfelling was not as disastrous as many people predicted			- within a few months of clearfelling, bare ground was covered with natural regeneration, but new growth was less diverse - in the clearfelled 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 1984

REFERENCES TO THE PHILIPPINES

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 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 1983
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 1984
Philippines	- tropical rainforest, Eastern Mindanao - general poor logging performance has resulted 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 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 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			Reyes 1978

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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 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 relog 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 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			Tabudar 1984
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 and Torres 1978

REFERENCES TO SOUTHEAST ASIA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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		Appanah and Weinland 1990
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	- 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	- felling damage to intermediated sized trees (dbh >30 cm) assessed to be 30% - wastage due to breakage and poor bucking 6.5-8% of the gross timber volume	- for 1974-1983 forest destruction occurred over an average 21% of the area logged per year	FAO 1989b (also in Thang 1987)
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 - 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	- 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 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	- in many cases half or more of the trees remaining after logging are damaged, some of them so badly 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 relogged forest often deteriorates into a state of unproductive weeds		Korsgaard 1985

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
Southeast Asia	- 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 bicyclic 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 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	- 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 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		- 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%	Nicholson 1979
Southeast Asia	- examples of sustainability criteria for dipterocarp forest management	- minimum felling limit 60 cm	- <20% felling damage to residual stem number - <15% extraction damage to residual stem number	- <15% of harvested area with bare soil exposure	Ong *et al.* 1996
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 are achievable with good management, it is wrong to use these numbers when conventional logging is practised		- a less severely damaged forest recovers more quickly after logging		Putz 1994

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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)			Serna 1986
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	Sundberg 1978
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	- with directional felling techniques about 200 m^2 of area is damaged per tree felled - if 15 trees/ha are felled 30% of the area would sustain felling damage	- 30% of the area sustains skidder damage	Weidelt 1996

REFERENCES TO INDIVIDUAL COUNTRIES IN SOUTHEAST ASIA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
Adaman 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 1988
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		Buenaflor and Karunatilleke 1992
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 - 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	- 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	Crome *et al.* 1992
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		Gajaseni and Jordan 1990
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 and Laurance 1996
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

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 - 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 clearfelling 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	Neil 1984
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	- minimum cutting diameter was 50 cm and logging intensity allowed was 8 trees/ha (23 m^3/ha) - 11-12 trees/ha with dbh >50 cm left as residual seed trees			Seppanen and Malvas 1986
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 1987
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 unmerchantable - 38 years after logging, tree marking in a previously logged stand reached the same selection intensity as in a virgin stand	- from the logging damage studies 10% of original stand stems were destroyed, while 11.5% were damaged but would probably survive		Vanclay 1989

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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 losing the productivity and health of the forest	- 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 destroyed		Watanabe 1992

REFERENCES TO SURINAME

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
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	- 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) 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%)	- 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	Hendrison 1989
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 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)	- 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 - damage is considerable, but the forest is not destroyed		Jonkers and Schmidt 1984
Suriname	- tropical rainforest - dbh growth in recently logged forests was 0.43-0.52 cm/a, compared to 0.36 cm/a in unlogged stands (trees with dbh >15 cm)		- with 15 m^3/ha logging intensity and RIL of 182 stems/ha (dbh >15 cm) 1.9% were felled and 82.2% had no damage - with 45 m^3/ha logging intensity and RIL of 169 stems/ha (dbh >15 cm) 6.9% were felled and 64.7% had no damage		Jonkers and Hendrison 1987

REFERENCES TO UGANDA

LOCATION	DESCRIPTIVE INFORMATION	LOGGING INTENSITY AND CYCLE	RESIDUAL DAMAGE AND UTILIZATION	SITE DAMAGE	SOURCE
Uganda	- tropical high forest - recommends a uniform silviculture system rather than polycyclic due to excessive damage to residuals during logging	- 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 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	Dawkins 1958
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		Kasenene and Murphy 1991
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 monodominance 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		Plumptre 1996
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 stems/ha, BA 19.0 m^2/ha, canopy cover @ 15 m 32%)	- 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		Skorupa and Kasenene 1984

APPENDIX C: LITERATURE SUMMARIES

Abdulhadi, R., Kartawinata, K. & Sukardjo, S. 1981. Effects of mechanised logging in the lowland dipterocarp forest at Lempake, East Kalimantan. *Malaysian Forester* 44(2-3): 407-418.

- 11 trees/ha removed (stump diameters ranged from 80 to 150 cm)
- 41 percent of the residual stand suffered branch and crown damage, 59 percent was undamaged
- the damaged trees were mostly located close to the tractor paths, skid trails and around the 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.

- average log conversion rate at the stump was 36.2 percent, with a maximum of 54 percent 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.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
- 12.2 percent 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. pp.76-77.

- harvesting >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*.

- gap opening per tree felled ranged from 350 to 1800 m^2
- felling 2.6 trees/ha in the Bura Forest Reserve in Ghana resulted in 13 percent logging disturbance
- canopy gaps account for 50 percent of the disturbance, skid trails 38 percent and haul roads 12 percent

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 (1971-1978) to 45 m^3/ha (1979-1990)

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

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 percent
- 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.

- hill forests in Peninsular Malaysia
- the 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 principle management systems for dipterocarp forests throughout Southeast Asia, although, some lowland dipterocarp forests are still being managed under the Malayan Uniform System (MUS)
- have the Philippine Selective Logging System (PSLS), Indonesian Selective Cutting System (ISCS), Selective Management System (SMS) of Peninsular Malaysia
- in the PSLS a logging cycle of 30-40 years with suitable tending is used
    * during the first silvicultural operation only 30 percent of trees with dbh between 15-65 cm and 60 percent 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
- 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 which should be carried out (e.g. pre-felling inventory, climber cutting, tree marking)
- important to all selective cutting is to retain sufficient numbers of trees in the 30-45 cm dbh class which 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 not to reduce 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/a. These references generally link back to a UNDP/FAO project in 1978, which has be 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/a)
- in SMS logging damage to residuals is estimated at about 30 percent 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 varied systems should be employed
- for SMS to work, firstly and of immediate concern is the improvement of logging practices
- outlines RIL

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 percent of standing trees in restingas (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 percent due to the heavy logging equipment, landings and roads

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/a, 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/a, 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/a 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/a for the skid trail and by 77% to 3146.7 kg/ha/a 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 percent 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 percent

Baidoe, J.F. 1970. The selection system as practiced in Ghana. *Commonwealth Forestry Review* 49(1): 159-165.

- selection system as practised 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

Bariteau, M. & Geoffroy, J. 1989. Sylviculture et régénération naturelle en forêts de Guyana française (Silviculture and natural regeneration in the forests of French Guinea). *Revue Forestière Française* 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 sawnwood, generally for local markets, required on average 1850 m^3 of logs for 650 m^3 of sawnwood per year (= 35.1% LRF)
- medium-size mills (generally one bandsaw, 30 people employed, n=41) required on average 10 200 m^3 of roundwood to produce 3500 m^3 of sawnwood (= 34.3% LRF)
- veneer and plyboard mills (n=5) 91 000 m^3 for 33 850 m^3 of processed wood (=37.2% yield), logs floated from as far as 2 500 km away
- in the varzéa 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]

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 percent of trees killed were 10-20 cm dbh, but this class only holds 63 percent of trees
- RIL reduced damage or death to trees from 48.4 percent to 30.5 percent (i.e. extra 95 trees/ha >10 cm dbh remained undamaged)
- in Borneo, damage often exceeds 50 percent, 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 percent and typically averages no more than 30 percent
- 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 have been major successes 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 underused 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 Programme, 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 percent of the actual log production [Bhargava and Kugan 1988]. Bhargava and Kugan [1988] also found that on average 9.4 percent of the actual log production was left as residues in the landings, and that almost 54 percent of the residue logs observed were free of any defects. The total utilizable waste based on removed log volume was 27.7 percent.
- 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
- 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/a
- sawmill recovery 50 percent and waste 50 percent (edges 12%, slabs 14%, offcut 7%, sawdust 12% and bark 5%)
- plywood mill recovery 44 percent plywood, wood residue 45 percent (log trim 4.4%, cores 5.9%, undried veneer 24.1%, dried veneer 8.5%, sander dust 2.1%), bark 11 percent
- of 1.9 million m^3 fed to sawmills, and veneer and plywood mills, 0.68 million m^3 are left as unutilizable
- 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

Boerboom, J.H.A. & Wiersum, K.F. 1983. Human impact on tropical moist forest. *In* W. Hozner, 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

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 percent 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 percent (45 cm min dbh) to 21 percent (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 percent and for the +70 cm class 40 percent (assuming based on stems in original stand)
- supervised setting 21B8R had 71.7 percent (20-60 cm class) and 46.6 percent (+70 cm class)(7 ha)
- supervised setting 21C8R had 65.2 percent (20-60 cm class) and 40.0 percent (+70 cm class)(6 ha)
- unsupervised setting 14 had 46.8 percent (20-60 cm class) and 23.0 percent (+70 cm class)
- unsupervised setting 13 had 26.1 percent (20-60 cm class) and 36.4 percent (+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 percent and for C8R it was 258 percent (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 percent, 30 percent decrease in yield and 20 percent 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 roundwood required to produce 1 m^3 of sawnwood 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.

Brotoisworo, E. 1991. Indonesian forest resources and management policy. *In* D. Howlett and C. Sargent, eds. *Proceedings of Technical Workshop to Explore Options for Global Forestry Management.* Bangkok, Thailand, 24-30 April 1991. International Institute for Environment and Development pp.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 percent
- 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 overcutting and relogging, aggravated by a lack of knowledge about enrichment planting and 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 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.

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

	Commercial volume, m^3/ha	Volume increment, $m^3/ha/a$	Time period, years
Tropical very dry forest[1]	31.3	0.58	15.2
- fire, grazed and logged	25.0	0.31	15.2
- undisturbed (average of 2 stands)	131.0	3.36	4.0
Tropical dry forests[1]	103.2	2.07	9.8
- fire, grazed	111.8	1.75	8.1
- fire, grazed, logged	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 year-old			
- 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* P. Kunstadter, E.C. Chapman and S. Sabhasri, eds *Workshop: agroforestry systems in Latin America*. CATIE, Turrialba, Costa Rica. pp. 209-210.

- rates of wood production based on short-term measurements (1-2 years) are variable and range from 2-11 t/ha/a, which are greater than in mature tropical forests of 1-8 t/ha/a

- 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)

Bruenig, E. 1996. *Conservation and management of tropical rainforests: An integrated approach to sustainability*. CAB International, University Press, Cambridge, UK. 339 pp.

- overlogging removes more than 50 percent, and up to 80-90 percent, 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 Peatswamp forest
- selective logging in Africa has little effect on the ecological conditions of the forests which 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, crawler tractors loosen, move and compact the soil on 20-60 percent of the area
- at the common cutting rate in MDF of 10-20 percent of the volume, proper selection felling with extraction by crawler tractor damages 20-30 percent of the basal area of the residual stand. The damage rapidly increases with intensity of cut, at 50 percent removal reaching 70-80 percent. Beyond this, the falling crowns and skidding smash practically the whole residual stand
- conventional selective logging as currently practised causes 70-80 percent damage with only 10-20 percent 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 outturns

- 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 skid trails, 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 percent fewer crop trees in the 40-60 cm diameter class are destroyed or damaged, so that more larger timber of high quality is produced in the next felling cycle
- Putz and Pinard [1993) found 50 percent damage to the residual stand in conventional logging
- Phillips [1993] found 43 percent 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 percent less damage to the residual growing stock
- in current selective logging 20-50 percent 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 m3/ha), which results to 33 percent 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 percent and the damage to the residual stand and the soil is reduced by at least 25-30 percent
- 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 skid trail 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 Peatswamp forest. Proper and orderly sustainable harvesting was introduced in the 1950s against initial opposition by most concessionaires. The results were reduced costs, improved working conditions and safety, and increased outturn 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%), skid trail area (-22%), canopy opening (-44%), loss of commercial residuals (-33%), abandoned merchantable timber (-48%), cost per m^3 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 skid trails, $35/ha for directional felling, $40/ha for drainage of roads and skid trails. 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 Peatswamp 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 percent 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 percent
- 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 indisciminate diameter limit cutting in Sarawak mixed Peatswamp 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 percent, 59.6 percent of residual growing stock severely damaged, 17.8 percent slightly damaged and only 8.2 percent 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 1950s
- 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 exist 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 clearfelling 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 (Peatswamp 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, overlogging 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. pp.37-76.

- (?) percent of all residual trees are damaged in polycyclic systems
- (?) percent of 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. 67 pp.

- a critical review of uncontrolled logging operations in PNG
- over 30 percent of most logged areas are destroyed by uncontrolled skidding
- over 40 percent 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 percent of residuals undamaged with logging intensity of 23 m^3/ha, while 78 percent undamaged in controlled with logging intensity of 32 m^3/ha; area damaged was 13.7 percent in uncontrolled and 11.0 percent 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 FAO:DP/PNG/86/009. 36pp.

- project deals with Manus Province
- assumed a 30-year cutting cycle and 0.75 cm/a diameter growth in AAC calculations, along with a 10 percent reduction for breakage and defects
- selective logging is not seriously practised 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 practise 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 No. 7. 103 pp.

- 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 percent 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.RW. 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 percent 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 km^2 (range 0.1-4.0 trees/ha)
- direct logging disturbance affected 8.4 percent of the area

- ± 14.7 m of tractor trail per tree extracted
- the mean size of gaps was 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 percent 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 percent (% of basal area) of the trees were undisturbed, 55 percent were destroyed in the extraction process and 10 percent 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, undoubtedly 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 percent of the pre-cut basal area, and 62 percent of the pre-cut dipterocarp basal area (5.7 m^2/ha in 6 months, 5.4 m^2/ha in 1 year, 4.1 m^2/ha in 8 years, mean 5.1 m^2/ha)
- residual dipterocarp trees <50 cm dbh suffered high mortality after logging, possibly limiting future wood production
- on an average 76 percent of the crown cover had moderate to heavy disturbance (45% heavy disturbance to the canopy)
- in the 6 months after logging in the area 18.4 percent of the forest floor was disrupted by roads, tractor tracks and skid trails, while after 1 year it was 14.0 percent and after 8 years 6.2 percent (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 percent and non-dipterocarps 38.5 percent; and in company operations to dipterocarps 32.8 percent and non-dipterocarps 34.5 percent

Catinot, R. 1994. Aménager les savanes boisées africaines. Un tel objectif semble désormais à notre portée (Managing wooded African savannas. Such a goal now appears achievable). *Bois et Forêts des Tropiques* 241: 53-70.

- in Côte 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 m^3/ha/a to 2-3 m^3/ha/a (regions 700 mm rainfall/year) and 3-3.5 m^3/ha/a (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, 6-12 August 1995*. IUFRO S3.05-00 and CIFOR Publication. pp. 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 percent were dipterocarps
- minimum felling diameter in Sabah is 60 cm
- 192 climbers/ha with diameter ranging from 2 to 32 cm, and dead trees accounted for 3 percent of stocking
- felling intensities exceeding 100 m^3/ha are common
- skid trail spacing was 60 m and was planned
- in directional felling 39 percent fell within 5º of intended lay, 63 percent within 10º of intended lay and 78 percent 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 percent 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/ha 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 percent 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 percent of the original number of seedlings present before logging were still alive 3 years after logging (19 350 seedlings/acre reduced to 2 450 seedlings/acre)
- the majority of the mortality occurred during logging (5 350 seedlings/acre 1 year after)
- there was no change in species composition of the live seedlings
- 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

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, 6-12 August 1995*. IUFRO S3.05-00 and CIFOR Publication pp.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 percent extracted, 11.85 percent very severe injury or killed, 3.25 percent severe, 12.36 percent minor injury, 68.5 percent had no injury, and non-logging damage was 2.75 percent
- in tractor logged area logging effect was 4.82 percent extracted, 19.15 percent very severe injury or killed, 0.86 percent severe injury, 14.06 percent minor injury, 60.66 percent had no injury, and non-logging damage was 5.26 percent

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 percent 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 which 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
- 3years 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 percent of their total stems and 25 percent of their total basal areas removed of which 57.6 percent was on harvested trees
- gully sites lost 16.6 percent of total stems and 17.1 percent of total basal area yet only 42.4 percent 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 per ha			Incidental losses, %BA		% canopy loss	Roads, % of area		Study
		Stems	m^3	m^2	Killed	Damaged		All	Minor[1]	
Queensland	5.6	26.0	66.0		16.0[2]		18.2	26.0		Nicholson and Cassels [1983)[3]
Queensland	1.6	32.7		15.4	29.9					Nicholson *et al*. [1988]
Queensland	0.1	39.5		24.8	21.3					Nicholson *et al*. [1988]
Queensland	0.4	18.9		7.3	16.0					Nicholson *et al*. [1988]
Queensland	0.6	25.6		11.4	29.4					Nicholson *et al*. [1988]
Queensland	0.3	18.2		8.4	28.9					Nicholson *et al*. [1988]
Queensland	0.2	19.8		9.0	35.8					Nicholson *et al*. [1988]
Queensland	19.0	6.6	36.6	4.8	18.1		19.4		4.3	This study
Queensland	16.5	7.6	42.1	5.6	20.4		22.3		4.8	This study
Sabah	43.7	11.6								Nicholson [1979] p.19
Sabah	8.1	15.3								Nicholson [1979] p.19
Sabah	8.1	16.6								Nicholson [1979] p.19
Sabah	4.0	19.0			58.0[4]					Nicholson [1979] Table19
Sabah	4.0	9.1			40.0[4]					Nicholson [1979] Table19
Sabah	4.0	12.8			51.0[4]					Nicholson [1979] Table19
Sabah	4.0	11.9			43.0[4]					Nicholson [1979] Table19
Sabah	4.0	16.1			47.0[4]					Nicholson [1979] Table19
Sabah	43.7	11.6	47.2		29.8[4]	45			14.0	Nicholson [1958]
W.Malaysia		13.7								Nicholson [1979] (Table 21)
W.Malaysia		8.4	41.6							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	21.3							9.0		Wyatt-Smith & Foenander [1962]
W.Malaysia		18.3		24.0	47.6	53.6				Johns [1988]
Kalimantan	2.0	11.0							30.0	Abdulhadi *et al*. [1981]
Philippines	10.0	24.6	244							Nicholson [1979] Table 26
Philippines	22.2	19.8	222							Nicholson [1979] Table 26
Philippines	7.6	20.5	187							Nicholson [1979] Table 27
Philippines	7.6	7.2						12.0		Nicholson [1979] p.29
Amazonia	6.8	8.0	52		11.0	28.0	46.3			Uhl and Vieira [1989]
Amazonia	52.0	4.3	31					8.0	4.0	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

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

- 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 [202 m^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 acre (405 m^2), and could have been reduced to one-half of this through directional felling
- if basal area is >140 ft^2/acre trees of THF are incapable of satisfactory growth
- basal area should be between 80 to 120 ft^2/acre 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/a = 2.1 m^3/ha/a), 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/a 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 percent 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 percent 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 percent 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 percent increase in machine maintenance and repair costs, while productivity decreased to as low as 15 percent of average dry season productivity
- pre-planning skid trails and directional felling could reduce the area covered by skid trails to 15 percent
- by restricting skidders to skid trails and requiring more winching the disturbed area could be reduced to as low as 4 percent, 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 techniques at least a 15-30 percent 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 where 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

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 20 m^3/ha (Brazil) ??? I get 10 m^3/ha based on Table 1 data
- 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 percent
- maximum canopy opening was 15 percent (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 3 800 m^2/ha vs 1500 m^2/ha in this study
- Uhl and Viera [1991] got 13.8 percent 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), 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

Dykstra, D.P. 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. 93 pp.

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 USA 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 roundwood production (mill.m^3)	Estimated felling recovery 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
LatinAmerica/ 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
USA	na	na	493.385	110.796	382.589	78

Estimated sawmill recovery rates for the three tropical regions around 1986, with data for the USA. provided for comparison

Region	Sawnwood 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 Am./Caribbean	25.424	34.415	42
Total	66.241	75.969	47
USA	88.065	122.667	42

Estimated plywood recovery rates for the three tropical regions around 1986, with data for the USA 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 Am./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 m^3 annual, or 89 percent of the total annual production of industrial roundwood

- about 60 percent 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 Roundwood 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 sawnwood 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 roundwood 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 sawnwood
= ---
Other conversion losses
= 1450.8 (16.8% of VSMILL)

Volume of sawnwood production (VSAWN)
= 3854.7 (44.8% of VSMILL)

Storage and transport losses
= 56.3 (1.5% of VSAWN)

Sawnwood delivered to market (VSDELIV)
= 3798.4

Premature degradation
= ---

Sawnwood 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 roundwood 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 percent 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 programmes to improve cross-cutting skills suggest that improved utilization of 20 percent or more and increased log values of 10-50 percent can be attained by such training
- although skid trails commonly represent 20-40 percent of the harvesting area, several studies have found 60 percent or even 80 percent of the area covered with skid trails after selection harvesting had been completed

Dykstra, D.P., G.S. Kowero, A. Ofosu-Asiedu & P. Kio, 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. 103 pp.

- 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 and 110 cm dbh are used in West Africa and vary by country and species (table given in report)
- in southeast Asia 33 percent of the total area and 33-67 percent 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, 6-12 August 1995*. IUFRO S3.05-00 and CIFOR Publication. pp.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	0-15	620	2	9.39
I	16-25	697	6	21.13
II	>25	748	17	35.43
III				
In PT, Kiani Lestari				
I	0-15	565	8	38.60
II	16-25	487	9	46.20
III	>25%	480	8	46.82

- 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 percent by felling
- canopy opening size ranged from 285 to 512 m^2/tree felled and averaged 396 m^2/tree felled
- mortality of residual trees 10-39 cm dbh was 6-26.6 percent during the harvesting year, 2-13.6 percent one year after, and 0.7-3.6 percent 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 percent per year (1.1% average)
- at NR the dbh growth of trees with dbh >10 cm was initially 0.55-1.25 cm/a after logging but reduced to 0.41-1.04 cm/a
- at NR the dbh and volume growth of 25 nucleus trees one and two years after logging were 0.92 and 0.50 cm/a, and 1.832 and 0.901 m^3/ha/a
- at KL the average dbh growth on trees >10 cm was 0.80-0.95 cm/a after harvesting, 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
- at KL the average growth of commercial trees with dbh >10 cm was 2.97 m^3/ha/a

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
- mean annual increments in the logged area were 0.71 cm/a and 0.36 cm/a, one and two years after logging
- mean annual increments for the corresponding years in the undisturbed site were 0.39 cm/a and 0.42 cm/a
- nitrogen and organic carbon levels were back almost to pre-harvest levels within 18 months
- chemicals such as calcium and potassium will take much longer to return to pre-harvest 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. 70 pp.

- 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*. FAO Forestry Paper No. 88. Rome.165 pp.

- soil disturbance 20-25 percent of logged area
- the TMF of Africa have a lower stocking of commercial species than in the MDF in southeast Asia
- big problem is what share of the growing stock is merchantable, because it 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 the second world war, there was a swing toward natural regeneration (1950-1960)
- 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 US$1 200-2 000 per ha, pines and eucalypts on savannah sites US$700-1 000 per 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 – (1 500-4 000 mm/a) 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 averages 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
- licences 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
- RIL should be used
- 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
- need a partnership between harvesting and silviculture
- Uganda - 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
- Côte d'Ivoire silviculture experiments with logging intensity – by removal uncommercial species by 30-40 percent of the basal area, growth of marketable species increased by 50-100 percent – 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*. FAO Forestry Paper No. 89. Rome. 228 pp.

- 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 practised seldom fits into the description usually found in silviculture textbooks 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 percent)
- drastic increase in light and change in moisture conditions encourage the growth of weeds, especially primary colonisers, 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

- clearfelling 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/a	
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/a	
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 assess felling damage to remaining intermediate sized trees of >30 cm dbh to be 30 percent
- wastage due to breakage and bucking 6.5-8 percent 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/a in commercial gross volume)
- however, necessary to limit logging damage to residual stand to not more than 30 percent 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 percent of the area logged per year, leaving an adequately stocked logged-over area of 79 percent
- this forests should yield and adequate logging volume after 30, 35, 40 or 45 years
- in ground-based systems 54.5 percent of residuals undamaged, while with high-lead yarding 43.3 percent 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
- e.g. tropical shelterwood system in West Africa lead, 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
- an 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 be 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/a. 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/a.
- if all you want is wood fibre then plantations come into question, although it is possible to grow sawlogs and veneer logs in plantations on longer rotations (5 to 10 times increase in increment when compared to a fully managed mixed tropical forest)

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

- 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 percent 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 techniques, 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/a, 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 practised, 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/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 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/a for predicting future volume availability
- **<u>good controlled logging is the only realistic silvicultural tool available for the management of the natural forests</u>**
- 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. 1997. *State of the world's forests: 1997*. Food and Agriculture Organization of the United Nations. Rome. 200 pp.

- 3 454 million ha (1995) of forest area or 26.6 percent 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, skid trails 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 percent and that damage to the residual forest stand can be reduced by more than 20 percent
- 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 sawnwood
- in the manufacture of paper and paperboard pulp from chips and roundwood only made up 56 percent of the furnish in 1994, where in 1970 it was 75 percent (i.e. increased use of recycled fibres, non-wood fibres and other additives (e.g. clay))
- global roundwood consumption 1994 was 3.21 billion m^3 (fw 1.890 and irw 1.476 billion m^3)
- forecasted roundwood consumption 2000 is 3.512 billion m^3 (fw 1.885 and irw 1.627 billion m^3)

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% per year) are compared with returns from the forestry sector (in the order of 3% per 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
- **<u>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</u>**

- 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 cooperatives 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). *Göttinger Beitrage zur Land und Forstwirtschaft in den Tropen und Subtropen* No.75. 226 pp.

- 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 which 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 to 80 cm

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 percent of residuals had little or no damage; with no climber cutting 26.1 percent had little or no damage (logged 1966), but results from 1958 showed 55 percent with little or no damage
- volumes extracted in treated in ft^3/acre (1752, 1780, 1788, 912, 1538, avg = 1554)
- volumes extracted in controls in ft^3/acre (2164, 1435, 1891, 3008, 2004, avg = 2100)
- considerable seedling loss due to tractor movement and approximately 43 percent 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 percent or 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 which 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 percent of the residuals had little or no damage, while 53.5 percent were fallen or broken off, and 12.9 percent 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 percent were damaged significantly or severely
- for trees felled at 6 ft or less 21 percent 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)

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 tenrec 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 practised 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 percent 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 planned 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 percent 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 occurs 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 >10 cm) 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 yields at the mills in Paragominas were low also
- saw timber yield was 35 percent (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 percent to 60 percent and for sawmills from 35 percent to 50 percent
- 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*. FAO Conservation Guide No. 1. Rome. pp. 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"

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 southeast Sabah the logging intensity between 1970 and 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 percent, under conventional (tractor) logging techniques, and 80 percent 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. 26 pp.

- a review of the literature on the effects of forest management and logging on biodiversity in the tropical and subtropical 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 percent
- felling gaps ranged from 100 m^2 to 1 000 m^2, with the average size being 380 m^2, resulting a total felling area damaged of 2.81 ha or 0.47 percent
- 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 percent of the total area
- total damage in area directly under roads, secondary damage and gaps is 26.41 ha or 4.39 percent of the study site (3 569 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 percent more damage than the best road system designed by the computer programme (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

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 percent
- using a waste rate of 30 percent the net extracted volume is 34 m^3/ha
- in a review of logged-over areas very few, if any, dipterocarp sawlog 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 sawlog size will mature 35 years after logging and that they will constitute the second crop in the following cutting cycle

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. 43 pp.

- a literature review on the topic
- 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 used 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

Heinrich, R. 1995. Environmental sound harvesting to sustain tropical forests. *IUFRO XX World Congress, Tampere, Finland, 6-12 August. Congress Report.* Vol. II. pp. 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/a compared to 2-8 m^3/ha/a from 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
- poor felling and cross-cutting, as well as poor knowledge of log grading rules, also result in volume and value loss; experience with training programmes to improve cross-cutting skills suggests that wood recovery can be improved by 20 percent or more, and the value of logs increased by 10-50 percent

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

- 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 percent 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 gives 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 programme
- 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 1957-1970 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 percent 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 percent (had more and larger felling gaps)
- skid trail area was 50 percent 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 percent vs 6.1-8.5 percent 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 aims 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 sawlogs 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 percent and the bearing capacity of the soil should preferably not exceed strength class 3 (????)
- with controlled logging the logging damage was reduced by 40 percent at a logging intensity of 20 m^3/ha, and skidding area was restricted to 5-7 percent compared to 14 percent 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
- <u>the extra costs of planning are returned by improved operational efficiency</u>
- <u>also, logging intensity on the next cycle can more or less be maintained at the same level</u>

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, 6-12 August 1995*. IUFRO S3.05-00 and CIFOR Publication. pp.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%)

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. pp.113-133.

- from 1974 to 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/a, with overstory removal 0.37-0.44 cm/a, and with liberation thinning 0.45-0.56 cm/a (in this case if only reserved trees measured 0.77-0.99 cm/a)

Hutchison, 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 Juan, Puerto Rico, 22-27 September 1986*. USDA Forest Service, Southern Forest Experiment Station. pp 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 percent of the total number of stems that existed in the virgin forest, snapped the trunks of 5 percent and injured more than 66 percent 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 percent of the basal area per hectare of surviving trees with fully illuminated crowns comprised stems with visible decay, while 20 percent were recorded as being totally decayed
- without an improvement cut a significant component of the growth will be on unmerchantable trees
- 40 percent 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 Northwest 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. Rome. pp. 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 percent of the felled trees easier to skid; about 40 percent 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 which 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. 208 pp.

Prospective timber yield - Cut-over 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
- m3/ha	3.4	3.8	15.4	18.8	22.0	27.8
Predicted harvestable volume by cutting cycles, m3/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						
- untreated	20.0	25.1	32.0	42.5	Growth	
- treated	28.3	35.8	53.4	68.9		
40 years						
- untreated	25.7	32.6	37.7	47.6	data	
- treated	33.2	42.4	63.8	82.4		
45 years						
- untreated	31.4	40.1	43.4	55.1	incomplete	
- 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 No.1. Yokohama, Japan. 18 pp.
- “To encourage the development of national policies aimed at sustainable utilization and conservation of tropical forests and their genetic resources, and at 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) lists 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. Yokohama, Japan. 5 pp.

- 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. Yokohama, Japan. 38 pp.

- 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. Yokohama, Japan. 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 clearfelling
- 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 US$2.05/$m^3$ or US$82/ha (does not include 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 = US$0.50/$m^3$ @ US$393.70/km of skid trail)
- 20 percent increase in skidding productivity results in a decrease from US$393.70/ha (US$9.84/m^3) to US$314.96/ha (US$7.87/m3) = US$1.97/$m^3$
- RIL cost = US$2.05/$m^3$ with a logging cost saving of US$2.47/$m^3$ or US$0.42/$m^3$
- 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 m^3/ha (5 trees @ an average 1.5 m^3/tree) of residual wood volume. Additional growth on these trees of 10 m^3/ha over a 25-year period could be expected, of which about 70 percent would be commercially recoverable timber. The overall additional wood fibre would thus be 14.5 m^3/ha after 25 years, which could work out to US$1 184/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 programmes, 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 “terra 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 naïve 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

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 percent (18 trees/ha) of trees (30 cm dbh) destroyed 50.9 percent (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 percent remaining trees 6.0 percent 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 percent of the stems were removed with 50.1 percent 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 terra firme rainforest in Amazonas State
- logged during 1975-1985 with a logging intensity of 3-5 trees/ha (main tree cut *Cedrelinga cateniformis*)
- damage was considerable at the time due mainly to careless siting 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. pp. 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 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 clearfelling of whole stands. The only exceptions are three operations (Colombia, Papua New Guinea, Sabah) where forests are clearfelled 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 as 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/ha depending on the forest type and country
- Malaysian dipterocarp forest up to 72 trees/ha felled (extreme which results 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 1980s, 8.4-13.5 m^3/ha for neotropical and African forests [Freezaillah 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 percent 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 percent 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 percent of the residual trees is common [Abdulhadi *et al*. 1981]
- post-harvest windthrow 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 siting 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 twice 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 m3 of timber extracted and less waste
- more than 80 trees/ha were spared damage with planned logging
- with planned logging damages can be reduced by 25-33 percent 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 1 503 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 programmes is to reduce logging damage in selection/selective cuts
- planning component in planned harvesting = US$72/ha
- logging efficiencies improved through sawyer finding trees quicker, skidder locating trees, skidding to landing – these efficiencies gain back about 13 percent 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 percent of the planning cost
- in the short term 25.4 percent 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. & 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 Juan, Puerto Rico, 22-27 September 1986*. USDA Forest Service, Southern Forest Experiment Station. pp.157-173.

- diameter growth in recently logged forest (trees dbh > 15 cm) was 0.43-0.52 cm/a, compared to 0.36 cm/a 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

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

- 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:
    * 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 oversized there is a temptation for the operator to use power instead of skill, while if the bulldozer is undersized too much winching and equipment manoeuvering, 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 percent reduction in cost through improved logging practices, while 5 m^3/ha or 7 percent more volume (based on a logging intensity of 60 m^3/ha) could be extracted through improved felling and bucking techniques

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 percent 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

Kilkki, R. 1992. *Reduction of wood waste by small-scale log production and conversion in tropical high forest*. Food and Agriculture Organization of the United Nations Forest Harvesting Case Study 1992:1. 33 pp.

- 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 to 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 percent
- 10.35 percent 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 roundwood 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 percent (44-56% range)

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 is 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 percent 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 US$14/ha or US$0.70/ha/a 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 No. 8. 78 pp.

- based mainly on work in Kuching, Sarawak, Malaysia
- at present the sustainable level of production is estimated at 2 to 3 m^3/ha/a 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 percent 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
- outlines RIL
- monocyclic systems have a rotation length of 70 to 80 years, are expensive and ecologically less desirable
- polycyclic 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 percent 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/a
- 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 naturally. 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**
- outlines in detail the reduced impact logging (RIL) technique

Kramer, R., Healy, R. & Mendelsohn, R. 1992. Forest valuation. *In* N.P. Sharma, ed. *Managing the world's forests*. Kendall/Hunt Publishing Co., Dubuque, Iowa. pp. 237-269.

- undervaluation 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)

Lamprecht, H. 1993. Silviculture in the tropical natural forests. *In* L. Pancel, ed. *Tropical forestry handbook*. pp.728-810.Heidelberg, Germany. Springer-Verlag.

- in the tropics proper forestry and silviculture are the exception
- only 1-5 percent of the tropical forests are under sustained-yield management
- the preservation of the tropical rainforests 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 tropical rainforest 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 1920s with bullock teams
- 14 species comprised 95 percent of the volume, and 4 species comprised 50 percent 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 which must be accounted for
- lack of planned skidways in the forest leads to the creation of numerous tractor paths for seeking logs

Leslie, A.J. 1977. Where contradictory theory and practice co-exist. *Unasylva* 29(115): 2-17.

- as a general rule logging costs generally account for 25-35 percent of the price of processed wood
- it is fairly common experience to find logging costs in tropical forests varying by as much as 50 percent 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 programme for sustainable management of tropical forests*. International Tropical Timber Organization Technical Series No. 7. pp. 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 tropics – 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 percent of the world's total hardwood sawnwood
- present and future value of the forest is enhanced by knowing how to efficiently process its wood

- sawmill recovery for United States hardwood mills is likely in the range of 45 to 55 percent
- sawmills in tropical countries will more likely process larger diameter logs (yield should be higher)
- in Africa more than 90 percent of the sawing machines are bandsaws
- in Ghana, lumber is not planed and average yield is 40 percent, increasing to 50 percent 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 percent, 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 percent (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 sawlog is 60 to 70 percent in sawnwood 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 percent
- 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

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 1960s 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 nor 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/a
- 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 1940-1950s 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/a 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 programme for sustainable management of tropical forests*. International Tropical Timber Organization Technical Series No. 7. pp. 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/a 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
- e.g. 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 shaded out (perhaps 15 years), but not so long that exploitable trees are lost due to overmaturity
- 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 forest. This extends to secondary forest products that are garnered in the forest, such as chewsticks, 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 1900s)
- 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 five years of logging the understorey 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 percent of the virola stand and at least 56 percent of the entire swamp forest. Due to inevitable damage to the residual stand the 56 percent of the entire forest is an underestimate
- Brazil's 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 percent of the logs were below the legal limit and it was estimated (based on form factors and regressions) that 70 percent 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 percent 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

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, 6-12 August 1995*. IUFRO S3.05-00 and CIFOR Publication. pp. 47-49.

- a 100 percent inventory of trees > 50 cm dbh in an Amazon forest, clay soils and slopes 0-25 percent 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 sawnwood
    - 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 percent of the area in the mechanically extracted area

- for the manual extraction area (kuda-kuda) the area of skid trails was 4 percent 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 No. 6. 90 pp.

- 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. 43 pp.

- study of RIL with tractor skidding and high-lead 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 percent of the area
- optimal (i.e. minimum) total area covered by roads, landings and skid trails slightly over 5 percent

Comparison of the number of advanced regeneration left per hectare after logging with supervised (48 ha) and unsupervised (21 ha) felling (tractor skidding)

Dbh classes	Supervised felling		Trees/ha remaining
	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 percent 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 No. 1. 108 pp.

- 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 percent 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 & D. Schöne, eds. *Dipterocarp forest ecosystems: Towards sustainable management*. pp. 293-307. Singapore. World Scientific Publishing Co. Pte. Ltd.

- 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 percent reduction in all measures of damage compared with conventional logging for an increase of about 10-15 percent 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 1 400 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 percent of the area, compared to 12 percent in adjacent conventional logging areas, of which 38 percent of the skid trails in the RIL area has subsoil exposed, while in the conventional area 87 percent 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 (5-60cm 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 percent 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 area 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 understorey 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 to 35 m with emergents reaching 50 m in height
- although 37 commercial species in the area, 75 percent of the volume extracted was "mureillo" (*Erisma uninatum* Vochysiaceae)
- minimum felling dbh is 40 cm
- felling with chainsaws and extraction with skidders
- for 1988-1993, 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 percent 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 2 000 (both countries have similar forest areas of about 20 million ha)
- in all tropical broadleaved forests only about 6.5 percent 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 and 0.5 m^3/ha/a
- the gross annual allowable cut (AAC) for intensively managed broadleaved forest is often estimated at between 0.5-1.0 m^3/ha/a, but can reach or surpass 2 m^3/ha/a
- 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 percent 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 percent of the coupe area was bared by logging operations in Insular Malaysia, while in 1965 the area bared was estimated to be 40 percent (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 percent 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.

- 1 403 live trees (742 10-30 cm dbh, 661 > 30 cm dbh) on a 4-ha research area tagged
- 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 percent 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 percent (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 percent 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 Document No.17. 76 pp.

- 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 towards 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 cases studies already presented in other reports [Mattsson-Marn and Jonkers 1981, Mattsson-Marn *et al.* 1981]
- 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. 15 pp.

- 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 percent, skidding efficiency increased by 36 percent (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 percent of area, while in current operations 30.4 percent
- both systems had 10.4 percent 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 percent to 30 percent 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 percent 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. 76 pp.

- 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 percent, overall damage to the forest was reduced by 33 percent, 50 percent 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 percent
- 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 percent (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 percent 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 which 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 $)

	$ 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

- m/ha of skid trail in unplanned area vs 136 m/ha in planned area (22% less)
- assuming 4 m wide trails 5 percent of area covered by trails in planned and 7 percent in unplanned
- logging damage was only calculated for commercial species
- planned area had 17.1 percent of areas as temporary open space vs 30.4 percent 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 in the planned area are 40 trees/ha vs 60 trees/ha in the unplanned area (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* P.B.L Srivastava *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. pp.27-38.

- harvesting operations utilizing detailed planning cost 20-45 percent 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 fewer 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 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 percent of the original stand was undamaged and non-defective after logging (based on stem numbers)
- 20.1 percent of original stand was naturally defective
- 21.5 percent of original stand had logging damage

Megahan, W.F. 1977. Reducing erosional impacts of roads. In *Guidelines for watershed management*. Food and Agriculture Organization of the United Nations Conservation Guide No.1. pp. 227-261. Rome.

- 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 ft^3/acre (= 69 m^3/ha)
- between 20 and 40 percent 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/acre) and unlogged plot (76 trees, 17 species, 34 273 ft^3/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, 5 834 ft^3/acre); unlogged (17 trees, 16 species, 7 853 ft^3/ha)
- 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/acre); less disturbed (15 dipterocarps 3-11 ft girth, 3 296 ft^3/acre)
- in the disturbed area the greatest volume (1 354 ft^3/acre) is occupied by *Anthocephalus*

- average dipterocarp forest in Sabah can produce between 18-30 ft^3/acre/a 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 which 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 provide 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 percent of trees in dbh class 40-60 cm, 80 percent in 60-70 cm dbh class and 100 percent of trees >70 cm dbh on a 35-year cycle, the optimum logging intensity was 71.9 m^3/ha

Miller, T.B. 1981. Growth 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/a
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/a			
	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/a net growth rate after logging is achievable (compared to their plantation growth rates of 12-20 m^3/ha/a)

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 programme for sustainable management of tropical forests*. International Tropical Timber Organization Technical Series No. 7. 157 pp.

Species	Cutting cycle,	Size of tree		Standing volume,	Harvest volume,	Uses	
	years	Height, m	dbh, cm	m^3	m^3	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 (teak)	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*. pp. 37-45. Food and Agriculture Organization of the United Nations.

- 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 percent of the residual stand damaged and up to 40 percent of the area crushed by bulldozers
- uncontrolled logging has a severe impact on biodiversity and ecosystem function, and 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 percent of the area
- RIL reduced the area of log landings by 50 percent

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 about 800 ha

	Reduced impact logging	Conventional logging
Roads	20 m/ha	24 m/ha
	1.6% of logged area	3.3% of logged area
Skid trails	71 m/ha	205 m/ha
	4% of logged area	13% of logged area
Log landings	57 m2/ha	103 m2/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 & D. Schöne, eds. *Dipterocarp forest ecosystems: Towards sustainable management*. pp. 603-615. Singapore. World Scientific Publishing Co. Pte. Ltd.

- since 1981, when the Indonesian Government blocked roundwood exports, followed by a total ban in 1985, 2 708 sawmills and 117 plywood mills have been built
- the large and medium-size mills are concentrated in Kalimantan (59.3%), with about 23 percent located in east Kalimantan
- logs produced accounted for 63.2 percent of the felled trees, with residue being 36.8 percent (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 from four logging sites totalling 130 ha
- sawmill recovery rate was 50 percent and residue 35 percent by volume for logs received at the mills
- plywood conversion efficiency was 42-65 percent, with an average rate of 55 percent

Myers, N. 1983. Tropical moist forests: Overexploited and underutilized? *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 percent 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

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 1960s and early 1970s logging was more selective and soil damage by extraction affected 10-15 percent of the area and the canopy was broken in places but by no means removed
- in the late 1970s, 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 percent of the area disturbed or compacted
- the result was a massive invasion of climbers which 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

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 percent of area

Nicholson, D.I. 1958b. An analysis of logging damage in tropical rain forest, North Borneo. *Malaysian Forester* 21(4): 235-245.

- 53 percent of residual trees were damaged
- fallen and broken off trees 30 percent, bark damage 11 percent, crown damage 4 percent, for total damage 45 percent
- trees with little damage 8 percent, undamaged trees of good form 35 percent, undamaged trees with poor form 12 percent, for 55 percent little or not damaged
- the volume extracted was 4.7 trees/acre (1 308 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 percent 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 percent of bared area in typical logging areas given by Nicholson [1958] is now very often exceeded and figures as high as 40 percent 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. Report FO:MISC/79/8. 65 pp.

- 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 1970s the literature on the situation in the late 1950s and 1960s 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/a 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 percent 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 percent 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/a, while a 40 year cycle 2.0-3.5 m^3/ha/a)
- it is reasonable to use a minimum figure of 1 cm/a 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/a can be used
- it seems quite clear that, even with the low degree of control being exercised over logging, 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/a 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 percent
- 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/a 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 roundwood that can generally be expected

  * sawnwood 56-68%
  * plywood 50%
  * waferboard 75-80%
  * strandboard 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

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 percent while in the supervised logging it was 33 percent
- the commercial logged area resulted in 55 percent higher water yield than the supervised logged area, although the percent of forest removal was only 21 percent higher (i.e. 40% vs 33%)
- skid trail density was 60 percent higher in the commercial logged area, and the ground disturbance (skid trails, logging roads, landings) was limited to 5.1 percent in the supervised area as compared to 7.1 percent 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 programme for sustainable management of tropical forests*. International Tropical Timber Organization Technical Series No.7. 163 pp.

- grows in PNG and NSW (Australia) to heights of > 60 m and dbh > 190 cm
- 45 000 ha of plantations since 1920s
- 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/a

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 percent extracted as log

Sawmilling yield: four countries compared

	Yield of sawn timber, %			Yield of wood residues, %		
	Main product	Total	Byproduct	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)		45		47	55	8
- dipterocarp (export market)		57			43	

- 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 & D. Schöne, eds. *Dipterocarp forest ecosystems: Towards sustainable management*. pp. 446-463. Singapore. World Scientific Publishing Co. Pte. Ltd.

- 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 US$1 100/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* F. Mergen & J.R. Vincent, eds. *Natural management of tropical moist forests – Silvicultural and management prospects of sustained utilization*. pp. 71-91. New Haven, Connecticut. Yale University, School of Forestry and Environmental Studies.

- 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

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 the1-ha plot there were 3 stumps, 670 trees (girth bh > 10 cm) left
- 17.7 percent of the residual trees were damaged
- 51 trees were knocked over (mostly in the >30 cm girth class)
- 8 percent of area bared, compared to 30 percent 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 & D. Schöne, eds. *Dipterocarp forest ecosystems: Towards sustainable management*. pp. 274-292. Singapore. World Scientific Publishing Co. Pte. Ltd.

- it was found that numerous indicators and their corresponding specifications already exist, however may be 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 means of natural regeneration	size-class harvested	- trees > 60 cm dbh and < 120 cm dbh	- tree marking
	trees retained (n/ha)	- protected species (e.g. fruit trees) - 5 trees/ha; dbh > 60 cm as seed source if regeneration is insufficient - potential crop trees (10-40 cm dbh)	- tree marking
Impact of felling	felling damage	< 20% of the residual	- directional felling

operation limited		stem number	- 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* N.P. Sharma, ed. *Managing the World's Forests*. pp. 337-373. Dubuque, Iowa. Kendall/Hunt Publishing Co.

- 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
- e.g. 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 noncommercial species or sizes, which was demonstrated to be highly damaging to regeneration more than 35 years ago – is still a problem in many countries

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 percent 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 percent 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 percent, while where RIL guidelines implemented it was 13 percent
- RIL areas skid trail coverage was 3.4 percent on average, while in adjacent conventional logged areas it was 12 percent on average
- % of trails with soil exposed was 38 percent in RIL areas, while for conventional areas it was 87 percent
- RIL results in at least 50 percent 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 percent of the cost of implementing the guidelines
- RIL results in reduced bulldozer maintenance cost (less sidecutting 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, m3/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 (CONV) 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 percent of the area is traversed by crawler tractors [Chai 1975, Jusoff 1991], and 40-70 percent 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 coordinated
- 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 percent of residuals damaged, similar to other studies done in Sabah
- RIL 27% of trees > 10 cm dbh were damaged and 19 percent were dead within the first year after logging
- CONV 54% of trees > 10 cm dbh were damaged and 46 percent were dead within the first year after logging
- logging damage in RIL was 50 percent 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 practised, 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 percent 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

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). Göttinger Beitrage zur Land und Forstwirtschaft in den Tropen und Sobtropen No. 43. 139 pp.

- 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/a 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 (42 800 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,	Logging	Calculated area	Percentage

	m^3	intensity, m3/ha	logged, ha	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 1940-1950s peaked due to waiving of the felling limit
- total area over the 60 years 26 638 ha or 62 percent 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*. 63 pp. Gland, Cambridge, UK. International Union for Conservation of Nature and Natural Resources.

- previous guidelines produced in 1976
- in the 10 years 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 practising 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, licences 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 which 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"

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*. Bogor, Indonesia. CIFOR Working Paper No. 4. 7 pp.

- 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 percent 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/a and that these unmanaged forests accumulate timber at an annual rate of 1.0 m^3/ha/a. 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*. pp. 15-26. Food and Agriculture Organization of the United Nations.

- 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 and 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 policies, 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 paid based on the volume removed, therefore they only take out the best and largest logs. This results in over 20 percent 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 US$27.00/ha
- volume of unextracted wood, due to felling damage or poor quality, can be from 20 to 25 percent 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 to10 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 percent and yarding damage 4-6 percent
- in tractor skidding felling damage to residuals was 9 percent and skidding damage 2 percent
- 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/a
- growth rates from various research results range from 1.60 m^3/ha/a to 8.55 m^3/ha/a

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 jeopardize 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/a)
- with a 20 percent increase in residual stand the harvestable volume is increased to 190 m^3/ha (3.33 m^3/ha/a)
- 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 1950s that 58 percent 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/a 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 percent healthy residuals were achieved
- there is a noticeable shift in attitude from predominantly exploitative-oriented to conservation-oriented logging

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. 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 clearfell logging operations in the Gogol valley, Papua New Guinea. *Ambio* 13(5-6): 351-354.

- clearfelling was not as disastrous as many people predicted
- within a few months after felling bare ground was covered with natural regeneration, but new growth was less diverse
- in the clearfelled area soil phosphorous was 50 percent 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 understorey species (plants, mammals, birds)
- 15.35 percent of all trees damaged in polycyclic harvesting vs 40-60 percent 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 Southeast 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 lose 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 speciality 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/a; thus 4 billion ha presently yield approximately 4 billion m^3 – a volume which could be hypothetically produced from 100 million ha of tropical plantations
- by portraying export-led industrial forestry as the primary threat to forest conservation [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. 11 pp.

- 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 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
- 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 been largely 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 percent 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 and 3 m^3/ha/a

- in plantations growth rates of 20 m^3/ha/a 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/a 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 strengthen 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. 1997. *Forest harvesting in the natural forests of the Congo: A case study*. Food and Agriculture Organization of the United Nations (in print). 68 pp.

- 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 cooperation with a large private contractor operating a concession in the Republic of Congo: about 150 000 ha of closed-canopy, broadleaved forest located in the Chaillu Massif in southern Congo, at the border to Gabon; annually harvest area is about 15 000 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 watercourses 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 percent (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 percent
- out of the study area, three well-defined stands totalling 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 of 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 percent 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 percent. On average 212 trees/km of skid trail were damaged, of which 5.9 are okoumé, again concentrated in the higher dbh classes. 46 percent 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 percent, and of trees 40-80 cm dbh (immediate future crop trees) it was 9 percent. The damage frequency for all species and size classes was 6.3 percent
- the soil disturbance survey revealed a total disturbed area of 8.4 percent of the annual coupe area: felling sites 3.8 percent, skid trails 2.7 percent, secondary roads 1.0 percent, primary roads 0.7 percent, and landings estimated 0.2 percent. 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 percent of the annual coupe is seriously disturbed by skid trails and landings and other 5.8 percent is slightly disturbed by felling sites and skid trails.
- 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 improvements toward the objective of sustainable forest practice are possible, by placing high priority on harvest planning and assessment.

Schmidt, R. 1987. Tropical rainforest 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/a 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, 21-26 May, Madison, Wisconsin*. pp. 159-164. USDA For. Serv. Forest Products Lab. p.159-164.
- paper mainly about Weyerhaeuser's experience in Indonesia
- rainfall 250-350 cm/a 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 licence 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 mature
- 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. 24 pp.
- 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 No. 15. 34 pp.
- the selective logging which is practised 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 which 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 residues 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. 42 pp.

- 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 – wastewood was 12% and 22% stemwood in cut-over, 11% and 17% left at collection sites
- study 2 – 12% and 18% waste in felling and bucking areas, 2.9% and 2.5% in log yard
- broken and defective logs were the major part of the woodwaste, and accounted for 15.5 percent when calculated on a clear bole basis and slightly higher at 17.5 percent when based on minimum 30 cm diameter
- study 3 – wastewood based on a clear bole basis was found to be 25.1 percent for Kalimantan and 21.9 percent for Sumatra (less here because closer to market, therefore, higher utilization rate)
- study 4 – the average wastewood was 19 m^3/ha (wastewood 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 wastewood in tropical rainforest is 24-26 percent (based on [stumpage volume - extracted volume] / stumpage volume ∗ 100)
- for a 30 cm diameter the corresponding waste wood figure is 32-35 percent
- for mangrove forest it is 9 percent and for teak forest 11 percent
- both large and small sawmill lumber yield is 45 percent and waste is 55 percent (sawdust 10%, slabs 25%, log trim 17%, others 3%)
- plywood mill yield 40 percent and waste 60 percent in 1981
- recent study showed plywood mill waste to be 45 percent (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 rainforests 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 (> 10 000 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, 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/a in unlogged and 4.8 m^3/ha/a 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 clearfelled and tractor tracks covered 24 percent of the mechanically logged watershed

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 tree fall 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, m2/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 affects factors such as aerodynamic roughness, windbreak protection by neighbouring trees, and soil cohesion
- conventional mechanized logging operations which destroy up to 50 percent 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 percent to maintain natural tree falls at an acceptable level

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 synthesize 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/a for Africa, 1-3 m^3/ha/a for Latin America and 2-4 m^3/ha/a 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 1964-1973 (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 percent of the total actual area of tropical moist forest has been affected by the officially reported exploitation for the officially reported roundwood production (without fuelwood). The unknown areas under illegal felling activities have to be added to these figures

Areas affected through exploitation (based on roundwood production 1964-1973)

	Roundwood production 1964 (1000 m^3)	Areas affected by exploitation (1000 ha)	Roundwood 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

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*. pp. 47-56. Food and Agriculture Organization of the United Nations.

- 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, 21-26 May Madison, Wisconsin*. pp. 167-173. USDA For. Serv. Forest Products Lab.

- 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 costs differentials are much smaller
- the relative logging cost for logging intensities less than 20 m^3/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 and 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. 33 pp.
- 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 Proj. Rep. TCP/FIJ/6652. 37 pp.
- 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 are 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

- in 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

Tabudar, E.T. 1984. The sustainability of Philippine forests. *Asia Pacific Timber Industries*, Oct. pp. 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 practise 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 to 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

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 rainforest in Guyana: With recommendations for forest management*. Wageningen, The Netherlands. The Tropenbos Foundation Series 14. 123 pp.

- in a lateritic area (Ekuk Compartment, Mabura Hill) logging increased the number of gaps by 50 percent as compared to natural forest, the increase in overall gap area was 400 percent 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
   * 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
   * 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
   * surrounding forest may buffer shortages in nutrients at a later stage by litter input
9. gaps should be as 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/a): 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 (m^3/ha/a): 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 percent
  = annual ingrowth: (% of marketable species growing in over 30 cm dbh limit) 0.6 percent
- 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 percent of the gross volume for trees < 60 cm dbh and 70 percent for trees > 60 cm dbh
- 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 percent 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 percent of intermediate-sized trees (30-45 cm dbh)

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 percent of residual trees had no damage
- 13.68 percent of the trees were overgrown with climbers (can weaken or deform trees)
- 1.67 percent of trees had bark damage
- 5.22 percent of trees had crown damage
- 0.73 percent had bark and crown damage
- 28.6 percent 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 pattern: sporadic disturbances such as tree falls 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 tree fall 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 *Shoria 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 colonized 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 m2 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 which 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 percent, 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

- in the first study area 52 m^3/ha (8 trees/ha) were extracted, amounting to 1.7% of all trees 10 cm dbh
- 26 percent 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 percent of the total stand basal area was harvested, while an additional 28 percent of the stand basal area being destroyed or severely damaged
- total forest canopy cover was reduced from 80 percent to 43 percent (46% reduction); however, Amazonian forests normally have only 5-20 percent 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
- in the second study area (52 ha) 8 percent 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 (9 250 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 5 380 m were built
    * tertiary trails (used only once to pull out a single tree) were 2.2 m in width and 2 180 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 percent reduction in basal area (usually 20-30 m^2/ha in pre-harvested stands)
- since stumpage is cheap in the area and forest logging rights sell for US$25-50/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 rainforest 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 Thailand. *Forest Ecology and Management* 46(3-4): 243-273.

- 2-3 m^3 of logs are required to produce 1 m^3 of sawnwood
- 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 averaged 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 percent
- 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 percent (area 1), 5.3 percent (area 2) and 6.7 percent (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 manoeuver
- canopy openings 8.1 percent of area

Uhl, C., Barreto, P., Verissimo, A., Vidal, E., Amaral, P., Barros, A.C., Souza, C. jr., 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 percent addressed the question of forest management, a mere 1 percent 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 percent in pre-logged forests to less than 50 percent following logging [Uhl and Vieira 1989, Verissimo *et al*. 1992]
- logging in Para currently results in the harvest of approximately 4 000 km^2 of forest each year, producing approximately 8 million m^3 of roundwood = 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 recovers to pre-harvesting 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 undervalued 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 percent 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 percent reduced damage to trees > 10 cm dbh [Johns et al. 1996]
- trained loggers were able to achieve a threefold 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 percent
- 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 US$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

- 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 percent of each harvested log, but could be increased to nearly 50 percent 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 sawnwood 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 between 60 and 100 cm dbh depending on the species; at least 50 percent 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.

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	2 145	69.8
- unmerchantable stem	355	11.5
- stem marked for removal, felled and removed	424	13.8
- stem marked for removal, felled and left as unmerchantable	36	1.2
Total stems	3 075	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

- 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

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 percent were installed during the 1980s, with average production for a one bandsaw mill of 4 300 m^3/a
- lumber yield is 47 percent or 2.13 m^3 of roundwood produces 1 m^3 of sawnwood
- 63 percent 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 percent broken stems, 11 percent 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 US$50-150/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 1970s 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 percent in control to 40-47 percent in logging areas (mean 45%)
- annual dbh growth increments of 0.8 cm/a (managed= vine cutting and thinning treatments) and 0.3 cm/a (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 percent
- management cost would be about US$5/$m^3$ extracted, but loggers only pay stumpage of US$ 1-3/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 bandsaw mill will on average produce 4 500 m^3/a of sawnwood mahogany from 9 900 m^3 of roundwood (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; approximately 1 100 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, 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)

Virtucio, F.D. & Torres, M.F. 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 to 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 3 000 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 3 000 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

Wagner, M.R. & Cobbinah, J.R. 1993. Deforestation and sustainability in Ghana. *Journal of Forestry* 91(6): 35-39.

- nearly 93 percent of all forest land in West Africa (Benin, Ghana, Guinea, Guinea Bissau, Côte 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/a
- 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 understorey 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 encouraged; 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 programme for sustainable management of tropical forests*. International Tropical Timber Organization Technical Series No. 7. pp. 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 percent of the stand or more
- when the cutting percentage reaches 65 percent 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 percent is used

- has been shown that, if the natural forest is managed at a stock level of 70-80 percent 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

Weidelt, H-J. 1996. Sustainable management of dipterocarp forests – Opportunities and constraints. *In* A. Schulte & D. Schöne, eds. *Dipterocarp forest ecosystems: Towards sustainable management*. pp. 249-273 Singapore. World Scientific Publishing Co. Pte. Ltd.

- volume increment, without deducting mortality, on an area of primary forest may range from 1-5 m^3/ha/a
- 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 percent of the area would have felling damage
- in addition about 30 percent of the area sustains skidding damage
- imperative that logging damage is minimized to both the soil and the residuals

White, L.J.T. 1994. The effects of commercial mechanised 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 percent of all trees present before logging [Ewel and Conde 1976, Whitmore 1984, Johns 1992]
- in 1988 it was estimated that 46 percent of Gabon's forest had been selectively logged at least once, and each year about 2 500 km^2 is logged; 60 percent of which has not been logged previously
- 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 percent after logging
- overall canopy cover was 93.4 percent and was decreased to 83.2 percent after logging
- 1.4 percent of surface area covered by a major road, 5.0 percent covered by secondary extraction roads (6.4% of area bare and compacted)
- 5.0 percent of surface area had skidder trails and 16.9 percent was covered by crowns of fallen trees
- 71.7 percent 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
- in adjacent area logged in 1986 roads covered 1.6 percent of site, skidder trails and secondary extraction roads made up 7.5 percent of site, and 51.2 percent of canopy suffered some disturbance
- in adjacent area logged 10-15 years prior roads accounted for 1.8 percent of area and skidder and secondary extraction trails 7.2 percent of area

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. Draft Report. 59 pp.

- 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 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
- pre-harvest 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 pre-harvest 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 (watercourses, 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 generated 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 tree 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 indicated 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 work place 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 work place 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				
- preconcentration	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	
	Actual		Planned		B/F09	
	Productivity m^3/h	Production cost, %	Productivity m^3/h	Production cost, %	Productivity m^3/h	Production cost, %
Commercial inventory		19.5		19.5		
Forest road		30.0		30.0		30.0
Road maintenance		7.5		7.5		
Felling	20.02	11.0	20.02	8.3	18.90	7.7
Pre-concentration	31.44	32.7	31.44	29.8		
Skidding	66.37	11.6	66.37	11.6	27.43	62.3
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, 1 200 m in length and covered 4 200 m^2 (18.7%)
- traditional skid trails 4.98 m wide, 2 646 m in length and covered 13 177 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 m^2	Coverage m/ha	Area affected, %	Coverage m^2	Coverage m/ha	Area affected, %
Roads	625	12.5	0.63	625	12.5	0.63
Skid trails						
- primary	3 500	100.0	3.50	13177	264.6	13.18
- secondary						
Landing	400		0.40	625		0.63
Total	4 525		4.53			14.40

- 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)

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 results in an accumulation of logging debris and opening up of the canopy
- of the 1 million ha burnt in Sabah in 1983, 85 percent had been logged over
- of the estimated 3.5 million ha of tropical forest burnt in Kalimantan, 77 percent 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)						
10-20	252	(27)	30	(9)	72	(9)
20-30	102	(18)	21	(6)	55	(13)
30-40	45	(11)	12	(10)	53	(13)
40-50	29	(9)	8	(6)	49	(18)
50-60	20	(5)	10	(7)	49	(19)
60+	35	(7)	31	(13)	38	(10)
Unburned plots (n=2)						
10-20	264	(70)	25	(7)	24	(6)
20-30	102	(4)	19	(2)	17	(1)
30-40	34	(1)	22	(1)	20	(3)
40-50	22	(1)	20	(9)	28	(10)
50-60	16	(1)	6	(1)	12	(9)
60+	42	(6)	32	(5)	25	(12)

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 percent, area covered by crowns 28 percent, area covered by boles 2 percent, = total 39 percent
- 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 practised, 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 percent 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 31 000 million m^3, of which more than 3 000 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 ^{m3}/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 m3/ha (13 trees/ha) logging intensity in MDF in Sarawak
- 50 percent of residual crop trees uprooted, broken or injured [Marn and Jonker 1982]
- Abdulhadi *et al*. [1981] found 60 percent of the residual stand undamaged with the extraction of 11 trees/ha
- studies in Sabah have shown only 34 percent 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

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GFSS/WP/06	Literature Synthesis on Logging Impacts in Moist Tropical Forests

The Global Fibre Supply Study (GFSS) of the FAO Forestry Department operates under the guidance of an Advisory Committee on Paper and Wood Products. The GFSS has produced the above-mentioned publications. To obtain a copy free of charge, please contact:

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Compiling information on forest harvesting intensity is essential to the discussion of sustainable forest management. This paper presents a bibliographic synthesis of important literature on logging impacts and reduced impact logging in tropical forests.

The emphasis is on statistics which contribute to the Global Fibre Supply Study such as logging intensities, cutting cycles and harvesting waste, residual stand development and site damage in non-coniferous tropical forests. This review was then used to provide background information for the modelling work explained in Working Paper No. 5 in this series.