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Economic assessment of reduced impact logging in Sabah, Malaysia.

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ECONOMIC ASSESSMENT OF REDUCED IMPACT LOGGING IN SABAH, MALAYSIA

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DEDICATION

TO MY PARENTS

WHO GAVE ME LIFE AND GUIDANCE

NORAH, BEATRICE AND DENNIS
FOR THEIR LOVE

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I thank the Almighty God for his grace, strength and protection
during the course of this research project.

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ABSTRACT

The economics of two selective logging systems were investigated in Sabah, Malaysia. Both logging systems employed chainsaws and bulldozers to extract timber. Reduced impact logging (RIL) differed from conventional logging (CL) in that it included comprehensive pre-harvest planning, pre-harvest climber cutting, stock mapping, tree marking, directional felling, and a set of environmentally-friendly skidding guidelines. RIL has been widely recognised as the logging technique to achieve sustainable utilisation of tropical forest. The main objective of this research was to compare the immediate and long term (60 years) economic costs and benefits of RIL with those of conventional logging (CL) practice in terms of timber and non-timber values. The suit of non-timber benefits included carbon, soil, non-timber forest product namely, rattan, water and wildlife values.

The study was carried out in Sabah, Malaysia within the Sabah Foundation forest concession. The primary source of data for this research came from a commercial project that was initiated between Innoprise Corporation Sdn Bhd (Malaysia) and the New England Electric Supplies (USA). The RIL project was aimed at reducing logging damage using RIL, hence, increase carbon sequestration potential in forest biomass.

The economic analysis comprised two parts, namely (i) an assessment of the logging impacts on the ecological parameters, and (ii) carrying out an economic cost–benefit analysis. Primary data were collected for the timber, carbon, soil values and rattan values using a system of rectangular plots. The water and wildlife values were based on secondary data from published information. To determine the timber harvest for the second cut, a forest growth model (DIPSIM) was adopted for this purpose. Similarly, the potential future carbon in the logged forest was projected using a carbon recovery model (C-REC). The valuation of the timber and non-timber values was based on the market price and opportunity costs techniques. Future costs and benefits were discounted at rates between 2 % and 10 % using standard method except where costs and benefits were not derived on annual basis.

The findings of this study showed that using RIL to harvest timber had reduced logging damage on the forest vegetation and soils by 50 % compared with CL techniques. Timber production per area logged was comparable with conventionally logged forest, but differed significantly when compared on per management unit basis. There were fewer skid trails and log landings in RIL forest. In addition, soil disturbances was lower on skid trails and log landings, hence, the negative effects of off-site sedimentation was reduced. The lower disturbance in the RIL forest resulted in higher timber stock for timber and non-timber product such as rattan. The timber yield for the second harvest from RIL forest was also higher compared with CL forest. However, RIL was more expensive than CL techniques under some assumptions and constraints. Non-timber benefits other than carbon in the cost–benefit analysis were relatively unimportant. Carbon prices were variable, ranging from negative prices, through prices quite comparable with other results, to very high prices.

The study concluded with justifications to relax the RIL harvesting guidelines that were pertinent to the area left unlogged in RIL. There was also a case for exploring alternative logging technologies such as helicopter logging to harvest the unlogged area. These air-borne technologies were conceivably costlier than ground based logging system, but the international community could share this burden in a united stand to strive towards sustainable utilisation of tropical forests.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Chapter 1: Introduction

1.1. Problem definition

The sustainable utilisation and conservation of tropical forests is now high on the world agenda. This message is visible in two separate international initiatives by the International Tropical Timber Organisation (ITTO) and the United Nations (UN), amongst others.

In May 1990, the ITTO launched its landmark policy Target 2000, now known as the Year 2000 Objective. ITTO members from 22 consumer and 25 producer countries of tropical timber undertook by the Year 2000 to engage in the export of tropical timber and timber products only from sustainably managed forests (ITTO, 1990).

Two years later in June 1992, the UN launched the Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil. Some 178 UN member countries reached a consensus to take a global perspective on forests and to examine all types of forests and all facets of their sustainability. The action plan for the 21st century on forestry issues is covered in the Document Agenda 21 (Chapter 11) supplemented by the non-legally binding Forest Principles (Dykstra and Heinrich, 1996). The four priority areas of development are:

- sustaining the multiple roles and functions of all types of forests and woodlands;
- enhancing the protection, sustainable management and conservation of all forests and the rehabilitation of degraded areas;
- promoting efficient utilization and assessment to recover the full value of the goods and services provided by forests and woodlands;
- establishing or strengthening capacities for assessing and systematically reporting data on forests and forestry activities, including commercial production and trade.

Since UNCED, several international initiatives have been working on the development of principles to measure and assess sustainable forest management. The *Helsinki Process* is a movement targeted for the protection of forests in Europe and has played a formative role towards the adoption of "Forest Principles" at the UNCED; the *Montreal Process* is the non-European Working Group for the conservation and sustainable management of temperate and boreal forests, and the *Tarapoto Proposal* is on the Amazonian forests for the tropical forest. A number of international non-governmental organizations such as the Forest Stewardship Council, the World Conservation Union and the World Wide Fund for Nature have also been working on similar initiatives (Radday, 1996).

All of these initiatives recognize two important issues about tropical rain forests. The first is that tropical forests, lying between 23° 27' North and South of the equator, are an essential biological resource that provides many benefits and services for our ecological, economic and social needs (Myers, 1989; Poore and Sayer, 1991). Forest economists group these benefits under *use* and *non-use* values. In the first category, the *direct use* values are benefits that can be utilized directly. These include consumable forest products like timber, and non-consumable benefits such as education and eco-tourism use. *Indirect use* values correspond to the ecological functions of forest, e.g. carbon sequestration, nutrient cycling and the like. *Option values* measure the amount that individuals would be willing to pay to retain the option of having future access to a given species or level of diversity. The *non-use* category recognizes people's willingness to pay for the existence of forest for cultural and heritage values. The sum total of the *use* and *non-use* values is a measure of the total economic value of tropical forest.

The second issue which these initiatives highlight is that the economic activity of humans has a profound impact on the environment. It is now widely recognized that tropical deforestation is the most severe form of man-made disturbance. Houghton (1990) reported that deforestation (comprising conversion and degradation of forests) in the tropics is taking place at an average of almost 14 million ha per year. In South-East Asia, deforestation is mainly due to fuelwood gathering and overgrazing. The second most urgent land-use problem for many tropical countries is shifting cultivation (Peters and Neuenschwander, 1988; Potter, 1990). Ranjitsinh (1979) estimates that five million hectares of forest in Asia alone are lost each year through shifting cultivation. The extent of grassland in naturally forested tropical countries reflects the cumulative effect of human occupation through slash and burn activity. However, its extent and effects vary depending on many factors such as the culture, the crops under cultivation, and the timing of cropping and subsequent fallowing. The third agent of forest disturbance is logging (a collective term for the set of operations commencing by opening up the forest and ending with transporting logs from landings to the port). Although logging is the least severe form forest disturbance (rarely, itself leading to complete forest conversion), it has received the most publicity in the past and recent years, as evidenced by a plethora of sustainable forest management guidelines developed by governments and non-governmental organizations (FSC, 1994).

The reason why most tropical logging does not destroy the rainforest is that only commercially mature trees are felled, while the rest of the trees are left standing. Selective logging as practised in tropical Asia, Africa and South America employs one of two systems i.e. polycyclic and monocyclic systems (FAO, 1989). Polycyclic systems involve the repeated selective removal of harvestable stems when intermediate-size trees become mature. Hence, the system is dependent on an adequate stock of advanced regeneration. The Malaysia polycyclic system, for example, prescribes a minimum felling diameter at breast height (DBH) of 35-45 cm with a felling cycle of 25-30 years. In Sabah, the system prescribes a minimum felling diameter of 55-60 cm DBH with a felling cycle of 60-80 years. Monocyclic systems, on the other hand, remove all harvestable stems in a single operation. The system relies on tending seedlings to produce the next crop, instead of taller advance regeneration. Wyatt Smith (1963) gives the minimum diameter for the unmodified Malayan Uniform System as 5-14 cm DBH.

While both polycyclic and monocyclic systems are designed to embrace ecological, economical and social considerations, they sometimes fail because of bad policies and mismanagement (Wyatt-Smith, 1987). The consequences of these failures are over-cutting of the forest resource and excessive logging damage to the soils and residual vegetation. These two areas have often been the main cause of failure in tropical forest management (Poore, 1992).

As a practical requirement of forest management for sustainable timber production, the volume of annual cut must not exceed the regenerative capacity of the growing stock. Over-cutting can take many forms from the classical case of accelerated cut to illegal logging. The underlying cause of this problem is often related to the policymakers' indifference to the biological constraints of the forest. Take the case where a particular policy is to increase foreign investment in downstream wood industries. If the resource were already scarce, this would place a heavy demand on the upstream sector to supply the wood needed to meet the policy. The likely solution under such circumstance is for policymakers to 'borrow' future annual allowable cut to meet the present wood volume needs. Another case in point is that legislators in a democracy have their own and their party's re-election as one of their important goals. This means that any measure which imposes large costs and few benefits obvious to the electorate over the next few years is unlikely to find favour, no matter how large the long term benefits. Thus, it is not surprising that politicians who must worry about the next election often tend to worry less about the long term effects of their actions (Lipsey *et. al.*, 1984). The problem could be resolved if there is political will and professional discipline to amend actions (Burgess, 1990). This subject is outside the scope of this study: nonetheless, it is a critical factor in achieving sustainable production from tropical forests.

Lack of control in logging operations is the most common reason for the failure of forest management that has devastating impacts on the forest ecosystems and environment (e.g. Gillman *et. al.*, 1985; Fox, 1968, Poore, 1992). This applies to the utilisation of both humans and machines in logging operations. For example, the improper use of mechanised logging using chainsaws and bulldozers in log extraction could cause excessive environmental damage (Hendrison, 1990). The most obvious damage caused by log extraction operations is the open spaces created in the forest area; up to 40 % of a logged forest can be occupied by roads, skid trails, log yards and camp areas (Lanly, 1982). Vines quickly infest these open spaces hindering natural regeneration (Fox, 1968; Putz and Appanah, 1984). Consequently, future growing stock is substantially reduced. Soil in these open spaces is usually compacted because of the repeated passes made by heavy bulldozers (Dias and Nortcliff, 1985). This greatly increases the water run-off and the flow of eroded sediments into rivers and streams (Gilmour, 1982; Douglas, 1990). The extent of the increase in soil erosion and sediment yield after logging, although less understood presently, suggests that it may increase to 20 times the original amount (Hamilton and King, 1983).

In harvesting 4-15 trees that represent only 2-10 % of the growing stock from a hectare of tropical forest, it has been reported that approximately 50-65 % of the remaining trees are damaged (Burgess, 1971; Marns and Jonkers, 1982; Johns, 1985). Such excessive stand damage is common with a harvesting system that uses chainsaws to cut and bulldozers to extract timber. Damaged trees may not survive through the next rotation and will impair the capacity of the forest to meet the future timber requirement of attendant wood processing mills.

The depletion of excessive timber stock by inefficient timber harvesting operations reduces the capacity of the residual forest to sequester carbon. In addition, there will be an increased in logging debris which increased the capacity of greenhouse gas emission as they decay. Trees have a role in mitigating global warming because atmospheric carbon is sequestered in tree biomass through the process of photosynthesis, and is also held captive in long-lived stocks of forest products such as those used in construction and furniture. Through the use of improved timber harvesting techniques, it has been demonstrated that additional amount of carbon can be sequestrated in trees (Pinard *et. al.*, 1995).

Logging also reduces the forest canopy cover and disturbs the soil system in a way that changes the nutrient budget in the forest ecosystem (Uhl *et. al.*, 1982). Nutrient losses of up to 15 % in living biomass are not uncommon in the form of extracted wood and logging debris (Bruijnzeel and Critchley, 1994). It has also been found that nutrient losses are much higher when the topsoil is removed as often encountered on roads, landings and skid trails (Anderson and Spencer, 1991). Nutrient deficiency is the single most important barrier to early growth of tropical seedlings in such environments (Nussabaum *et. al.*, 1995).

From a hydrological perspective, the reduction in canopy cover allows more rainfall to reach the forest floor through the newly created gaps and increases the soil moisture content. The increase in surface runoff may cause flash flooding. In one study at Bukit Berumbun in Peninsula Malaysia, total water yield increased by about 70 % upon harvesting 40 % of the standing stock (Abdul Rahim and Harding, 1992). Peak discharges in storm-flow usually increase as a result of logging and were associated with downstream flooding (Bruinjnzeel and Critchley, 1994).

The negative effects of tropical logging on non-timber forest products (e.g. medicinal plants, essestial oils, resins, gums, latexes) has been well documented (e.g. de Beer and McDermott, 1989). Rattan is by far the most important non-timber forest product in Southeast Asia with Malaysia being one of the major producers of processed rattan. Rattan is also one of the most important non-timber forest products in Sabah besides bird's nest, damar, wild orchids etc. In the last two decades, the total value in export trade for finished rattan products from Sabah has increased by several folds from 1988 estimated at about RM28 million (de Beer and McDermott, 1989). While the impact of selective logging on naturally grown rattan stockings is not very well understood, it is obvious that reducing logging damage in terms of soil disturbance and openings for roads, skid trails and log landings can reduce the negative impacts.

Many species of wildlife respond to the spatial and temporal structural changes of the forest caused by logging in ways ranging from total withdrawal to multiplication. Certain generalizations can be made. Animal species that depends on undergrowth, large fruit trees, or a continuous canopy suffer the most negative effects due to the impact of logging. On the other hand, browsers, and those adapted to using scattered, unpredictable food sources like small fruit may benefit (Shelton, 1985).

Given such impacts, there are increasing demands (e.g. Jonkers, 1987; Hendrison, 1990; Hawthorn, 1993; Verissimo *et. al.,* 1992) and opportunities (e.g. Schroeder *et. al.,* 1993; Pinard *et. al.,* 1995; Heinrich, 1995; Sizer, 1996) for logging practices that reduce the ecological and environmental impact of timber extraction. Recent advances in timber harvesting using chainsaws and bulldozer systems, that have made them less damaging to tropical forests, have been attained by integrating comprehensive pre-harvest planning (e.g. Marn *et al.*, 1981; Hendrison, 1990) with sound harvesting practices (e.g. Ward and Kanowski, 1985). For example, Hendrison's (1990) work in Surinam found that felling damage in planned logging was only 8 % compared to 14 % with unplanned logging. The area disturbed was 5-8 % and 14 %, respectively. Timber production under planned logging was 8 to 10 trees ha^{-1} equivalent to 20 m^3 ha^{-1} and was twice that of unplanned logging. In Brazil, Johns *et. al.* (unpubl.) found that introducing directional felling coupled with an efficient lay-out of skid trails and log landings would reduce the number of trees damaged by 33 % compared with unplanned logging. The ground area occupied by open spaces was reduced by 31 % with improved logging. Under Malaysian conditions, Marn and Jonkers (1982) found that the total area disturbed in planned and unplanned logging amounted to 28 % and 41 %, respectively. Damage to the growing stock in planned logging was half that of unplanned logging while extracting 13 trees or 53 m^3 ha^{-1}. Similar work elsewhere in Malaysia found that planned logging can reduce damage to soil and vegetation by 50 % compared with unplanned logging using bulldozer systems (Putz and Pinard, 1993). However, Abdul Rahim and Harding (1992) found that water yield in a catchment logged by planned logging increased by only 37 % compared with 70 % in a catchment logged by unplanned logging as measured against the control catchment. The magnitudes of increase in water yield after logging were, however, strongly influenced by variation in annual rainfall. With unplanned logging, suspended solids concentration and turbidity levels were 12 and 9 times those of the control catchment, respectively. With planned logging, there was only about a two-fold increase of both suspended solids and turbidity (Zulkifli and Suki, 1994).

However, these preferred techniques of harvesting timber have rarely gone beyond the experimental scale. Jonsson and Lindgren (1990) gave several reasons for the lack of wider interest among the forestry community, among them:

- there is a lack of planning and control
- concession agreements, incentives and payment schemes do not stimulate sustained yield management
- forest operators focus on cost minimization and profit maximization
- forest enterprises have been accustomed to high profits and are reluctant to accept any reduction in short term profits
- knowledge acquired through research has not been effectively disseminated resulting in forest enterprises and loggers failing to realize the need for change

Perhaps, the single most important constraint on the advancement of improved harvesting techniques is the uncertainty about its economics. One line of reasoning for this position has been put forward by ITTO (1996) in that "evidence that improved harvesting systems are cheaper than conventional logging will encourage loggers to use these techniques, while evidence to the contrary may retard their widespread introduction". If low-impact logging is to receive a wider acceptance beyond experimental successes, there is also a need to communicate the economic viability of environmentally sound harvesting practices beyond just the timber benefits to include the many non-timber benefits of tropical forests. This broader view of forest economics is particularly important because it integrates all the direct and indirect uses of the forest, and the effects external to the boundaries of the forests in the analysis that makes forest management or practices economically sustainable (FAO, 1993). In the absence of a fuller analysis, this may simply reveal ignorance among concessionaires and forest enterprises of the total benefits brought about by best harvesting practices. The incentive for these agents to include environmental values may be a special niche market for their wood products that will command a price premium or through tax incentives. However, these incentives have not yet had a large impact on the industry.

1.2. Research objectives and scope

The objective of the present research is to compare the immediate and long term (over 60 years) economic costs and benefits of reduced impact logging (RIL) techniques with those of conventional logging (CL) practices in terms of timber and non-timber values. The scope of the research is to assess and compare the ecological and economic impacts of RIL and CL logging techniques in terms of timber, carbon, soil, minor forest products (i.e. rattan), water and wildlife values. These factors were selected because of their economic importance and relevance to the impacts of selective logging. The study has also limited the scope to six forest values which is manageable within the constraints of time, financial, technical and human resources;

The appraisal is based on an economic approach on the assumption that the ultimate objective of forest management is to ensure forests make the maximum possible contribution to human welfare (Gregerson *et al.,* 1987; Pearse, 1993). This social objective is frequently reflected in the forest policies of tropical and temperate countries. The move from traditional financial to economic analysis of forestry projects is also well recognised among economists in acknowledging the non-revenue producing benefits and external effects of natural forest (Leslie, 1987; Price, 1989; Barbier, 1992).

1.3. Relevance of study

The study described in this thesis is intended to contribute to an understanding about the economics of improved harvesting systems under real and commercial conditions. It differs from other studies (e.g. Marn and Jonkers, 1982; Johns *et. al.,* 1996) in that it evaluates the costs and benefits of improved harvesting systems by taking into consideration both timber and non-timber benefits in the analysis. The study has relevance to Principle 37 of the ITTO guidelines for the sustainable management of natural tropical forests which states:

"Management for timber production can only be sustained in the long term if it is economically viable, (taking full account in the economic value of all relevant costs and benefits from the conservation of the forest and its ecological and environmental influences)"

1.4. Thesis outline

There are ten chapters in this thesis. Chapters 1 identifies the problem associated with the need to adopt improved logging practices and more importantly, why there is slow uptake of such techniques in the world. This leads to the definition of the research objective and its aims. Chapter 2 describes the setting of the study area including its location, and the forests and forest practices of Sabah, Malaysia. In chapter 3, the framework of the economic analysis is outlined and a description is provided of the methodology used in data collection and analysis as well as the identification of the economic analysis and valuation techniques. The next six chapters (chapters 4 to 9) deal with the economics of timber, carbon, soil, rattan, water and wildlife values. Chapter 4 examines the timber benefit which has the dominant influence on the economics of the first and second harvest. In chapter 5, the costs of sequestering carbon using RIL and CL techniques were estimated. Soil is featured centrally in two chapters: 6 and 8. In chapter 6, the economic costs of the loss of forest (timber) productive capacity due to the damage of soil on skid trails, roads and landings is examined; and in chapter 8 the costs of the impact of eroded soil as downstream sediment are estimated. The comparative economics of rattan as one of the most important non-timber forest products was investigated for the study area and is the focus of chapter 7. In chapter 9, the economic value of animals in RIL and CL forest were estimated and compared over the full crop rotation of 60 years. Finally, chapter 10 is a synthesis of the whole research project, it includes an overall cost-benefit analysis and conclusions and recommendations.

Chapter 2: Study area and its setting

2.1. Geographical location of study

The research was carried out in Sabah, one of the two East Malaysian states situated on the island of Borneo (Figure 2.1). With a land area of 7.4 million ha, Sabah occupies about one tenth of the island of Borneo and is bounded by Sarawak (the second Malaysian State on Borneo Island) and Brunei to the west, and by Indonesian Kalimantan to the south.

The total population of Sabah in 1996 was estimated at 2.52 million, equivalent to about 24 persons per square kilometre (Statistics Department of Sabah, 1996). The population of Sabah is low by comparison to other Malaysian states but is increasing by 6 % per annum.

Sabah is known as the "land below the wind" because it is situated just outside the tropical typhoon belt. It has an equatorial climate that is warm and humid. Daily temperature varies from 28°C to 35°C and humidity between 70 % and 90 %. Sabah receives rainfall all year round with average annual precipitation of 3,390 mm (Statistics Department of Sabah, 1996). Rainfall distribution is influenced by two monsoon seasons. The north-east monsoon starts in October and lasts until February while the south-east monsoon occurs between May and September.

The landscape of Sabah comprises mountain ranges along the West Coast and undulating terrain in the centre and the East Coast. The Crocker Range of the West Coast runs in a NNE direction that peaks at Mt Kinabalu, the highest mountain in South East Asia, and flattens out in the central part of Sabah. The eastern part of Sabah contains low-lying areas interspersed with hills. Volcanism was more active in eastern Sabah resulting in the intrusion of igneous rocks into the sedimentary formation. More than nine-tenths of Sabah are underlain by sedimentary rocks, mainly shale, sandstone, chert and limestone. These sediments were deposited under the sea during the Tertiary and Quaternary period and since then have been compacted, folded and uplifted to their present varying heights above sea-level. Soils are generally derived from the siliceous sandstone and basic rocks from the uplands with the exception of volcanic soil in eastern Sabah. The soils in the lowland areas comprise alluvium, sandy loams and clay loams (Acres *et. al.,* 1975). The equatorial climate and soils of Sabah sustain plant growth all year. It is one of the few places in the world where it is still possible to find pristine tropical rain forest. The wealth and variety of the forests of Sabah have enabled the existence of endemic species of fauna not found elsewhere.

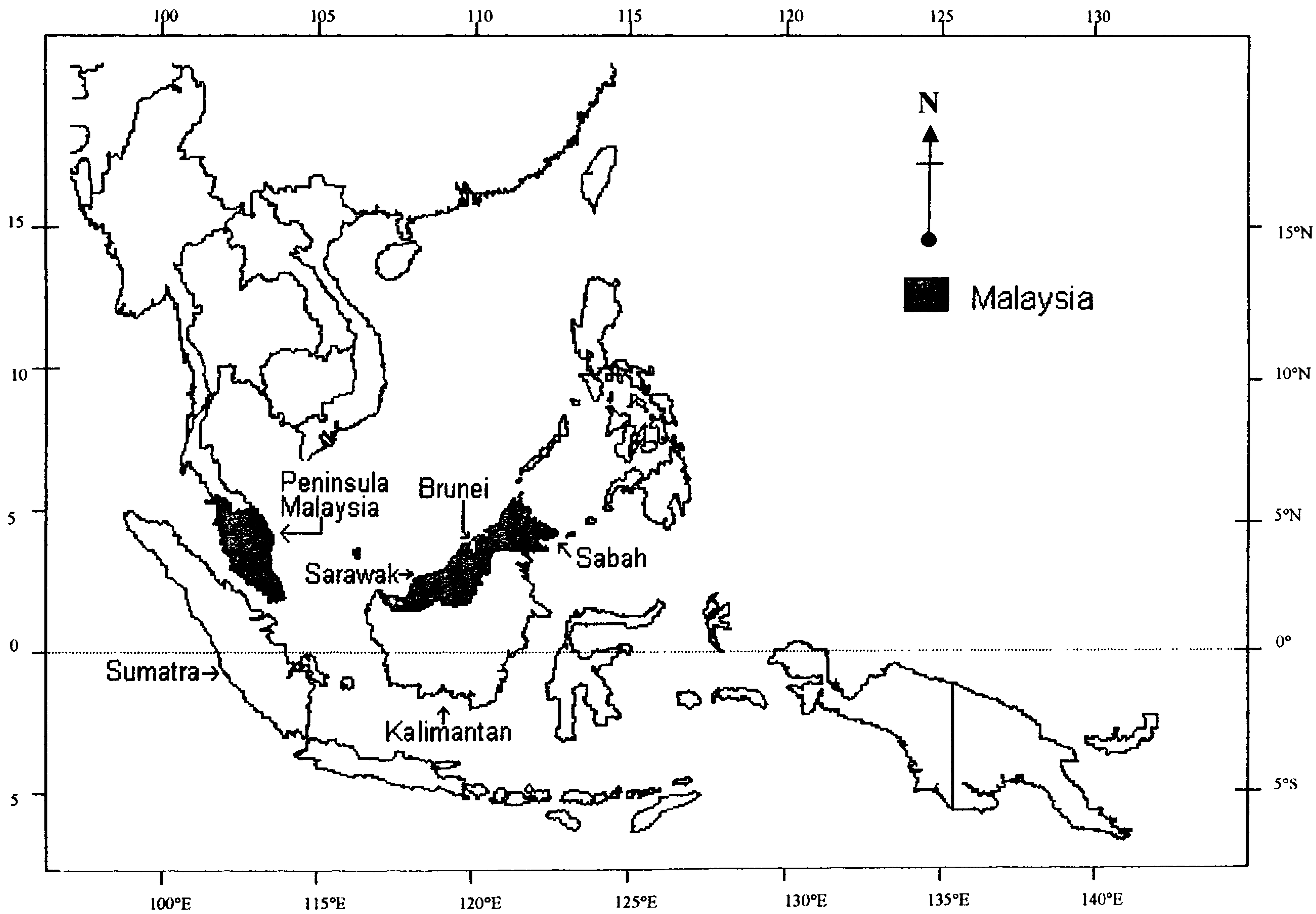


Figure 2.1 Map showing location of the Malaysian State of Sabah where the study was sited

2.2. Overview of the forests and of forestry in Sabah, Malaysia

2.2.1. Forest resource

About 62% of Sabah's total land mass of 7.37 million ha was under forest cover in 1995 (Table 2.1). Out of the total forest area of 4.31 million ha, 3.59 million ha or 49 % of the total land area is designated as Forest Reserve. The remainder of Sabah's land mass consists of State Land Forests (48%) and National Parks (3%). State Land Forests are outside the Forest Reserves and are mainly used for agricultural development (Sabah Forestry Department, 1989).

Forest Reserves (FR) are land that has been enacted and gazetted by law to be protected, managed and administered for specific purposes. In the case of Sabah, there are seven classes within the FR each serving a definite function (Table 2.1). Briefly, Protection Forest Reserve or Class I Forest Reserve is mainly for water catchment and there are 28 forest reserves of this type with an estimated area of 99,977 ha. The Commercial Forest Reserve (Class 2) is for the production of timber, and is the most extensive by area totalling 2,674,576 ha. The bulk of the forest sector revenue is derived from this class of forest reserve. Domestic Forest Reserve (Class 3) is reserved for local people to obtain firewood for fuel and building materials for village houses. This type of forest reserve comprises 7,355 ha and is located in 10 different areas throughout the state of Sabah. Amenity Forest Reserve (Class 4) is for recreation purposes and is found in 11 locations with a total area of 20,767 ha. Mangrove Forest Reserve (Class 5) is for the protection of the mangrove forest ecosystem that includes mangrove trees and a breeding place for fishes and other aquatic life. There are a total of 316, 457 ha of this class found in 17 locations throughout the State. Virgin Jungle Reserve (Class 6) is primary forest that has been set aside for scientific research and educational purposes and comprises 88,306 ha. The seventh type of reserve is Wildlife Reserve. The main purpose is for wildlife sanctuary. In Sabah, only two wildlife reserves have been enacted and gazetted, and these are the Tabin and Kulamba Wildlife Forest Reserves. Their total area is 141,203 ha.

Within the Forest Reserve, the forest is made-up of over 1,000 plant species in 267 genera that can reach timber size (Cockburn, 1976a and b). Most of the marketable timber species are found in the family Dipterocarpaceae (Wood and Meijer, 1964; Sabah Forestry Department, 1970). There are at least eight genera and over 160 species in this family with the main genera comprising *Shorea*, *Parashorea*, *Hopea*, *Dipterocarpus*, *Dryobalanops*, *Anisoptera*, *Vatica*, and *Cotylelobium*. The Dipterocarp forest of Sabah may be classified into two broad classes by elevation, i.e. lowland and montane. The

Table 2.1 Classification of land use in Sabah

Land classification		Area (ha)	Percent (%)
1. Permanent Forest Estate			
1.1 Protection	Class 1	29,4582	4%
1.2 Commercial	Class II	2,732,753	37%
1.3 Domestic	Class III	7,355	<1%
1.4 Amenity	Class IV	20,767	<1%
1.5 Mangrove	Class V	316,024	4%
1.6 Virgin Jungle	Class VI	90,382	1%
1.7 Wildlife	Class VII	132,653	2%
sub-total		3,594,516	49%
2. State Land			
2.1 With forest cover		474,440	6%
2.2 Non Forest (agriculture land)		3,057,140	41%
Sub-total		3,531,580	48%
3. National Park		245,172	3%
Grand Total		7,371,268	
a) Forested area (Items 1 + 2.1+ 3)		4,559,300	62%

Source: Statistics Department of Sabah, 1996 lowland forests extend up to an elevation of 750 m above sea level, and above which the forest changes in structure and species composition into that of the montane type. Sabah's main timber resource lies in the lowland Dipterocarp forests. This forest type is characterised by a wide range of trees occurring in a wide range of diameter (1-150 cm DBH) and height (up to 45 m) classes. The tree density is relatively high, with many trees in the lower diameter classes (approximately 3,000-5,000 trees ha^{-1} between 1 and 60 cm DBH) and few very large dominants and co-dominants (10-20 trees ha^{-1} greater than 60 cm DBH) (Burgess, 1961; Fox, 1967; Whitmore and Burnham, 1984). Climbing plants such as rattans, lianes, creepers and epiphytes co-exist in this type of forest. Much of the low-lying portion of the Dipterocarp forest has already been logged leaving only the hilly and steep portions unlogged (Marsh and Greer, 1991).

2.2.2. Forestry in the Sabah economy

The forestry sector plays a significant role in the socio-economic development of Sabah. It contributed on average about 56 % or RM2,000 million of the annual state revenue during the period 1970-1995 (Table 2.2). From 1970 to 1990, revenue from forest constituted more than 50 % of total State revenue (except 1985) with a maximum of 77% in 1979. Since 1991, the contribution has declined to less than 50% (except in 1993) and the latest estimate for 1996, is 41%. Since 1985, the forestry sector has registered a reduction in GDP share from 28% in 1978 to only 7% in 1995 (Table 2.3).

The impressive past revenue performance by the forest sector is attributed primarily to royalties collected from the sales of logs and timber cess from value-added products such as sawn-timber, plywood, veneers and others (see Appendix 2.1 for an explanation of royalty). From 1970 to 1978, log production had increased drastically from a low of 6 million m^3 to a high of 13 million m^3 (Table 2.4). During the 1980's, log production averaged 10 million m^3. In the 1990's, log production declined to 6 million m^3 annually until 1994. Sawn-timber production in Sabah, however, increased steadily from 936,000 m^3 to a high of 2.3 million m^3 between 1983 and 1993, and subsequently dropped to 1.5 million m^3 by 1995 (Table 2.5). During the same 13-year period, plywood production increased from 18,115 m^3 in 1983 to a high of 1.3 million m^3 by 1995. Veneer production showed a similar trend of increase as in sawn-timber and plywood between 1983 and 1993 but declined sharply in 1994 and 1995 due to stiff competition from Indonesia (ITTO, 1993).

Two forest policies have had a significant impact on the timber production scenario in Sabah. The log export quota was introduced in 1986 to redirect export-oriented logs for domestic consumption in view of the State Government's decision to go for value-added products. The log ban was introduced in 1993 to ensure that timber

Table 2.2 Contribution of the forest sector to Sabah's total revenue (1970-1995)

YEAR	STATE REVENUE (RM'000)	FOREST REVENUE (RM'000)	% FOREST REVENUE TO TOTAL REVENUE
1970	176	80	45
1971	183	96	52
1972	169	78	46
1973	299	184	61
1974	380	240	63
1975	266	152	57
1976	558	327	59
1977	716	497	69
1978	777	510	66
1979	1440	1110	77
1980	1538	1099	71
1981	1206	783	65
1982	1482	984	66
1983	1316	805	61
1984	1336	701	52
1985	1156	504	44
1986	1100	553	50
1987	1412	1001	71
1988	2038	1081	53
1989	1744	912	52
1990	1610	818	51
1991	1480	700	47
1992	2005	857	43
1993	1332	703	53
1994	2238	687	31
1995	1475	603	41

Source: Statistics Department of Sabah, 1995

Table 2.3 Gross domestic product share (%) of the forestry sector and other sectors in Sabah (1978-1995)

YEAR	FORESTRY AND LOGGING	AGRICULTURE AND LIVESTOCK	MINING AND QUARRYING	MANUFACTURING
1978	28	10	25	3
1979	24	11	25	4
1980	20	13	21	4
1981	24	13	16	4
1982	22	15	20	4
1983	22	14	22	4
1984	18	17	21	4
1985	18	18	19	5
1986	16	21	20	5
1987	17	23	19	6
1988	15	25	18	7
1989	12	23	22	8
1990	10	25	21	9
1991	10	26	20	10
1992	13	26	17	10
1993	10	27	14	14
1994	8	27	13	15
1995	7	28	12	13

Source: Satistics Department of Sabah, 1995

Table 2.4 Log production in Sabah (1970-1996)

YEAR	LOG PRODUCTION	EXPORT SALES		LOCAL SALES	
	M3	M3	%	M3	%
1970	6,559,782	6,146,550	94	395,232	6
1971	6,952,188	6,561,100	94	391,088	6
1972	8,525,737	7,714,700	90	811,037	10
1973	11,102,942	10,130,050	91	972,892	9
1974	9,921,003	9,733,500	98	187,503	2
1975	9,118,362	8,991,012	99	127,350	1
1976	12,636,293	12,103,184	96	533,109	4
1977	11,916,087	12,337,265	104	421,178	4
1978	13,289,035	12,375,082	93	913,953	7
1979	10,786,970	10,332,238	96	454,732	4
1980	9,062,949	8,510,441	94	552,505	6
1981	11,730,102	9,361,200	80	2,368,902	20
1982	11,739,262	9,949,666	85	1,789,596	15
1983	11,991,410	94,995,489	792	2,495,921	21
1984	10,504,738	7,339,578	70	3,165,160	30
1985	10,757,425	8,442,266	78	2,315,159	22
1986	9,811,078	8,692,939	89	1,118,139	11
1987	12,174,345	10,264,404	84	1,909,941	16
1988	10,980,563	8,237,700	75	2,742,863	25
1989	9,494,113	6,134,300	65	3,359,813	35
1990	8,443,725	4,562,700	54	3,881,025	46
1991	8,163,409	3,304,093	40	4,859,316	60
1992	11,632,596	3,422,201	29	8,210,395	71
1993	9,291,020	977,577	11	8,313,443	89
1994	7,964,781	0	0	7,951,020	100
1995	6,519,990	0	0	6,319,989	97
1996	5,638,090	0	0	2,665,085	47

Source: Sabah Forestry Department, 1996

Table 2.5 Export volume of timber products from Sabah (1983-1995)

YEAR	SAWNTIMBER (m3)	PLYWOOD (m3)	VENEER (m3)	OTHERS (m3)
1983	936,000	18,115	464,105	n/a
1984	855,000	31,300	164,000	n/a
1985	983,000	24,800	127,200	n/a
1986	924,000	37,400	117,200	n/a
1987	908,377	99,300	132,427	n/a
1988	1,033,232	128,351	136,569	n/a
1989	1,400,600	142,900	177,800	n/a
1990	1,962,000	154,200	274,700	n/a
1991	2,150,200	189,600	436,700	n/a
1992	2,262,900	372,300	621,500	n/a
1993	2,296,300	826,600	405,800	255,510
1994	1,914,300	1,170,300	228,600	431,159
1995	1,527,400	1,382,300	194,500	544,944

Source: Statistics Department of Sabah (1995) mills had a sufficient supply of logs due to increasing demand. The effects of these two policies are reflected in the reduction in the export of logs and the corresponding increase in processed wood products over the past two decades.

One of the major spin-offs from the bullish forest sector has been employment of 80,000 people in 1995 which accounted for 13 per cent of total employment in Sabah (Statistics Department of Sabah, 1996). This was a substantial increase over the 1990 estimate of 27,517 jobs but the increase was mainly in the wood processing mills. There were 318 mills in Sabah in 1994 compared with only 150 mills in 1990.

2.2.3. Natural forest management

By the Federal Constitution of Malaysia, the legislative and executive authority over forest is a State responsibility (Sabah Forestry Department, 1989). However, forest development plans are prepared within the overall perspective of national objectives. This common approach to forestry is facilitated by the National Forestry Council (NFC) that falls within the ambit of the National Land Council (Sabah Forestry Department, 1989). The role of the Federal Government in forestry matters is mainly confined to research and development, maintenance of experimental and demonstration centres, education and training, forest industry development, and technical assistance to the States in terms of overall forestry development and management.

The Sabah Forestry Department administers all forestry matters under the provision of the Sabah Forest Enactment 1968 (Sabah Forestry Department, 1974), which is the principal forestry law in Sabah (Christy, 1987). The Forest Enactment provides for forest reserves, and their use and management, as well as for control of cutting and removal of forest produce from "State Land" (publicly owned land which is not a forest reserve). In addition to the Sabah Forest Enactment 1968, the planning of State Forest is based on the State Forest Policy that was first adopted in 1954 with further amendments made in 1974. The State Forest Policy contains statements about the role and functions of the forest, their contribution in maximising social, economic and environmental benefits for the State, and the management of the forest in accordance with the principles of sound forest management (Sabah Forestry Department, 1989).

Among the seven classes of forest reserves, only commercial reserves (Class 2) are open for exploitation. Administratively, the Forestry Department issues timber licences to remove forest products from the commercial forest reserves as well as State Land forests (land to be alienated from forest for agricultural development). There are presently three main types of timber licences, namely Concession Agreements, Special Licences and Annual Licences. Concession Agreements are long term licences for 25 years or more. The size of the concession areas ranges from 2000 ha to 80 000 ha. Special Licenses are issued for five years. These licences are renewable and the area is variable. Annual Licences are valid only for one year and the areas are smaller than special licenced areas. As at December 1992, the total area under concession amounted to 80 % of the production forest (Burgess, 1988). These concessions are bound by concession agreements entered into between the State Government of Sabah and the licensees for extracting timber. The concession agreements have adequate provision to ensure the orderly and efficient sustainable management of forests. Each forest concession has a Forest Management Plan. The Plan contains a description of the area, the objectives of management or prescription on how the forest management unit is to be harvested, penalties for harvesting damage etc. Logging within a forest concession is controlled by a system of coupe approvals. The number of logging coupes issued each year depends on the annual allowable cut as approved by the Sabah Forestry Department. Each coupe permit is valid for such periods as may be specified therein but not exceeding five years, and upon expiry it may be extended, otherwise future entry requires another approval (Sabah Forestry Department, 1974).

Within all forest concessions, the silvicultural management of forests was based on a monocyclic system operating under the Uniform System established in 1956. The Uniform System was originally conceived in Peninsula Malaysia around 1948 in response to the increase in areas being opened for exploitation that necessitated a more cost-efficient and pragmatic silvicultural system (Ismail, 1966). The Malayan Uniform System (MUS) requires only a single felling and removal of all mature commercial timber species so that loggers can meet their high capital investment in the operation (Wyatt-Smith, 1987). The basis of the Uniform System is the presence of an adequate stocking of shade tolerant seedlings on the forest floor at the time of logging that could respond favourably to the opening created by logging (Fox, 1968). The goal was to develop a stand containing trees of 58 cm DBH on a 70-year rotation (Wyatt-Smith, 1963).

The sequence of operations involved in the MUS starts with a diagnostic sampling that is carried out a year or so before felling as a means of finding out whether a forest is adequately stocked with seedlings of the regenerating species. This determines whether the forest can be opened for felling or whether felling should be delayed if it is inadequately stocked. Felling is intended as the single commercial exploitation of timber trees. Following felling, a poison-girdling operation is carried out on the remaining non-commercial trees to liberate the seedlings of commercial species from light and root competition. The next series of operations under the MUS is regeneration sampling followed by poison-girdling of the remaining unwanted species and climber cutting, if necessary. Another survey is carried out 8-10 years after felling to assess the regeneration status.

The MUS was first implemented in Sabah in 1956 and treatments covered all major forest concessions in the subsequent years with 140,995 ha being treated by 1971 (Nicholson, 1965; Schmidt, 1987). The MUS as practised in Sabah introduced certain refinements to the original MUS for specific sites and circumstances, and emphasised post-harvest sampling to determine appropriate silvicultural treatment (Table 2.6). Main variations to the original MUS were a longer felling rotation of 60-80 years instead of 40-50 years, with a minimum felling diameter limit for commercial trees at 60 cm DBH; a different sequence of treatments, size limits, species to be poison girdled, means of improvement of regeneration, tending, etc. (Sabah Forestry Department, 1972). In the main, the Modified MUS (MMUS) prescribes climber cutting operations and protective marking of pole-size commercial species two years before the felling operation commences (1st silvicultural treatment), followed by poison girdling operations immediately after felling (2nd silvicultural treatment). A regeneration survey is carried out 5-10 years after felling, and a silvicultural treatment of these forests 10-15 years after felling (3rd silvicultural treatment).

The MMUS was enforced in Sabah until 1977 when the Forestry Department stopped all silvicultural treatments of forests. The decision may have been prompted by two separate studies evaluating the effectiveness of the MMUS treatments. Liew (1973) found that logging damage was so high that the 1st silvicultural treatment of protective marking and climber cutting did not serve its purpose. The cost of treatment was also too expensive for state-wide implementation. He suggested imposing rules and regulations in logging operations to achieve the objective of the 1st silvicultural treatment, i.e. restriction of the number and size of landings; restriction of the number of tractor paths; retention of seed-bearer trees and climber cutting. In another study, Chai and Udarbe (1977) cast doubts on the effectiveness of the 2nd silvicultural treatment of post-logging diagnostic sampling and poison girdling of competing vegetation. They reported that uncontrolled mechanised logging practice resulted in only one-third of the area being effectively treated and the remaining area being invaded by weeds, a condition favoured by the excessive canopy opening due to logging. Chai and Udarbe (1977) also contended that the rapid expansion of logging areas had made it impossible for silvicultural treatments to keep pace and resulted in a substantial backlog of untreated forest. Hence, it was uneconomic to treat the logged forest. This led to further modification of the MMUS whereby post-logging silvicultural operations are now confined to regeneration surveys at 5 years and 10 years after felling. The results will determine the need for and the type of silvicultural treatments (Lee, 1982).

Table 2.6 Sequence of operations of the Modified Malayan Uniform System (MMUS)

Timing	Operation
n - 24 months	Allocation of coupe
n - 12 months	1st silvicultural treatment – protective tree marking and climber cutting
n months	Felling operation
n + 0 to 1 months	Clearance inspection
n + 0 to 2 months	Assessment of regeneration through linear sampling milliacre (2 m x 2 m plots);
n + 3 to 6 months	2nd silvicultural treatment – first poison-girdling of unwanted and defective trees, climber cutting if necessary
n + 10 years	Assessment of regeneration through linear sampling Half-chain survey (10 m x 10 m plots)
n + 15 years	3rd silvicultural treatment – liberation treatment where necessary

n = time of felling operation

Source: Sabah Forestry Department, 1974

The MMUS has been successful in areas where there is sufficient seedling regeneration at the time of logging and where logging is adequately controlled. In Sabah, these pre-requisite conditions are not always satisfied because of the uneven natural stocking in rough and variable terrain due in part to irregular seeding of the preferred tree species. Secondly, logging damage to residual stands is relatively high, particularly in steep-slope logging. Hence, a blanket prescription of the MMUS over the forest is not cost-effective and is unsuitable for fully utilising the natural potential of the forest (Fox and Chai, 1982). Thirdly, constant pressure from the forest industry for a greater volume of wood from logged forests is inclining policy-makers to place a greater reliance on advanced growth to form the next crop (Tang, 1987; Kleine and Heuveldop, 1993). For these reasons, the current silvicultural strategy for the remaining primary forest in Sabah is to harvest trees with minimal impact on the residual stocking, relying on advance regeneration to provide the next harvest in 40-60 years (Chai and Awang, 1989), i.e. a "conservative approach" reverting to the large diameter cutting limits expected of a polycyclic system whilst strictly maintaining the cutting cycle (60 years) of the original monocyclic MUS. The silvicultural treatments of logged forest vary from liberation thinning to enrichment planting based on the results of a diagnostic sampling that is carried out immediately after logging (Udarbe and Chai, 1992).

2.2.4. Logging practices in Sabah

Timber harvest planning in Sabah is based on area control and is managed through a system of annual coupes. These coupes are first identified using 1:50,000 scale maps with contour intervals at 50 m. Each coupe is about 1,000 ha and may be further sub-divided into logging compartments of about 200 to 300 ha each. Coupe boundaries usually follow natural features (such as ridges or rivers) and are cut, and paint marked by the survey team. On major rivers, it is required by law that vegetation buffers between 20 m and 100 m wide are left intact to prevent adjacent logging debris from entering the water bodies. Logging is prohibited in these vegetation buffers. Timber cruising of the coupe is carried out by systematic sample lines. After the survey and inventory information is collected, it is analysed and sent to the Forestry Department for issue of the logging coupe permit.

Before harvesting a coupe, the licensee must first construct roads to gain access to the coupe. There are three types of logging roads in Sabah, i.e. main, secondary and feeder roads. The main logging roads are the principal artery of the road network and are surfaced for all-weather use. The width of the main road is between 6 and 11 m with road gradients up to 9 % adverse. Secondary roads are narrower (4 to 6 m) with gradient up to 9 % adverse. The third type of road is feeder tracks that are used by bulldozers in skidding logs. The width of feeder tracks is only big enough for skidding machines to pass through with their loads. The adverse gradient of feeder tacks is up to 20 %. During road construction, bulldozers follow marked trails and knock down vegetation along the right-of-way but trees with a DBH down to 45 cm DBH are salvaged. To help the main and secondary road surface dry faster, vegetation within a 20 m span is cut back on either side of the road.

Road density varies greatly depending on the terrain, soil and machine used in road construction. In one study, a logging company operating in hilly to steep portions of a forest concession in Sabah constructed a total of about 44 km main and secondary roads within a logging coupe of 2,033 ha. This gives a road density of 21.59 m ha^{-1}. With an average road width of 7.83 m, total area road coverage within the coupe is about 20 % (Malvas, 1987). During road construction, and in cases where the road falls on hilly and broken terrain, side-cutting was necessary and careless disposal of earthwork materials invariably resulted in serious soil erosion, and siltation of river beds and water basins (Malmer, 1990; Douglas *et. al.,* 1990)

Timber harvesting in Sabah employs one of two systems, i.e. ground skidding using bulldozers or high-lead yarding using portable steel towers mounted on truck carriers. The normal harvesting system in Sabah is, however, ground skidding that utilises bulldozers to extract logs following the felling of trees with chainsaws. The bulldozer is used for extraction because of its versatility for use in building roads and skid trails as well as for skidding logs (FAO, 1977).

During the logging operation, tree fellers comprising of a one- or two-man team locate commercial trees and fell them with chainsaws. All trees above 60 cm DBH are felled except those with visible defects (e.g. rotten branches) which are left standing, as are fruit trees and trees of less than 60 cm DBH. The fellers own and maintain their chainsaws and are paid on a piece-work basis. Generally, fellers have complete freedom over the direction and method of fall (Nicholson, 1958). Consequently, felling damage can be excessive and as much as 12 % of the residual stand suffers crown and bark damage while another 62 % suffers total damage (Fox, 1968). The extent of damage is largely determined by the felling intensity, i.e. the number or volume of trees felled per hectare. In the case of Sabah, the felling intensity is 8-15 trees ha^{-1} of trees above 60 cm DBH which yields 80-150 m^3 ha^{-1}. The abundance presence of climbers or lianas, averaging 500-800 stems ha^{-1}, also has a significant influence on felling damage. When lianas or climbers link tree crowns, a falling tree can pull down and uproot neighbouring trees (Fox, 1968; Appanah and Putz, 1984; Campbell, 1990).

After a tree is felled, it is trimmed to a log length of about six metres. Logs are then removed to roadside using bulldozer. The bulldozer belongs to the company and is manned by one operator and an assistant (hookman) who are paid on a piece-work basis. The bulldozer team determines the layout of the skid trail having conducted a brief reconnaissance of the logging compartment to determine the terrain and location of trees. This method usually leaves a pattern of skid trails that is undesirable by many other criteria.

Skidding is a log extraction process where one end of the log is hitched onto the tractor winch and dragged along the ground. Skidding is done along a track that has been cleared by bulldozes over a distance of 200-300 m depending on the terrain. On undulating terrain and in dry conditions, the bulldozer only runs over the topsoil to gain access to fallen trees. In such cases, the log will cause the only noticeable soil disturbance. On steeper slopes or in wet conditions, however, more frequent blade work is required to give ground traction to the bulldozer. The extent of soil disturbance caused by skidding is determined by the type of machine used, soil characteristics and weather conditions at the time of skidding (Hendrison, 1990). In a study of bulldozer skidding damage in Sabah, Fox (1968) reported that damage to the ground surface on tractor paths affected 43 % of the total logged area. Chai (1975) and Chai and Udarbe (1977) confirmed this figure.

Skid trails usually end at the secondary road where the logs are collected either on the roadside or at log landings. Where log landings are used, these are temporary log collection points of an irregular shape and vary from 0.2 to 0.5 ha. Here, logs are debarked, trimmed, numbered, measured and identified. They are also assigned a quality grade according to the Sabah Log Grading Rules (SLGR, see Appendix 2.2 for a full description). Log quality greatly influences the price of logs and has a large impact on a company's profitability. Under the SLGR (1980), there are nine classes of log grades (Class I to IX). In practice, however, Class I (Prime Grade) and Class II (Second Quality) are rarely used because of the strict admissible log defects in these classes. Most of Sabah's logs are classified into the Class III (Fair Average Quality - FAQ), IV (Superior Sawmill Quality – SSQ) and V (Sawmill Quality – SQ). In addition to the FAQ, SSQ and SQ grades, there are two other grades described in the SLGR. These are the Millable Quality (MQ) and the Millable Small (SM) quality that are recognised by the Sabah Forestry Department (Chaiyapechara, 1988).

Logs are then loaded onto logging trucks and transported to a dumping point, which is usually sited along a river. At the dumping point, the logs are made up into rafts and towed along the river to a log pond. The log ponds are the main collection and distribution points. At the log ponds, log rafts from the dumping points are received, checked, sorted, graded, scaled for royalty and payment and finally sold to buyers. Logs that sink in water (sinkers) are transported by barge to local mills or onto ships for export.

With high-lead logging, the machines used are mobile tower yarders with main-line pulling power exceeding 3,000 kg driven by 350-450 hp engines (Malvas, 1987). This system is designed for steep-terrain logging above 25° where tractor skidding is considered less environmentally-friendly. The impact of high-lead logging on the forest has not been documented in Sabah, but in the Philippines, Weidelt and Banaag (1982) reported that 57 % of the advance regeneration may be destroyed. It is common to find damage in high-lead logging occurring over a cleared radius of 10 m or more around the spar tree or log landing to provide space for log stocking and for the safety of crew and machine, as well as within 1,500-2,000 m of cable ways.

2.2.5. Improved forest management

In 1989, the Sabah Forestry Department (SFD) with the assistance of the German Government through Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) started a project aimed at introducing forest management practices which would sustain timber production in the 2.5 million ha of commercial forest in Sabah (Kleine and Heuveldop, 1993).

The SFD-GTZ system provides for thorough planning, implementing, monitoring and controlling at two levels i.e. State/Forest Sector Level and Forest Enterprise Level. At the State/Forestry Sector Level, the overall economic and social framework is evaluated and strategic plans are prepared. This forms the basis for the management of the forest enterprises. At the Forest Enterprise Level the system analyses the whole range of management activities to be carried out in order to achieve sustainability to meet economic, ecological and socio-economic objectives. The orientation at the Forest Enterprise Level is towards mimicking the natural growth dynamics of forest, retaining a mosaic of different succession stages, minimising harvesting damage, diversifying forest utilisation and safeguarding the local value added (Kleine and Heuveldop, 1993).

Forestry operations are conducted at the compartment level, and each compartment ranges from 200 ha to 300 ha. Timber harvesting is carried out with reduced-impact logging techniques. These techniques incorporate climber cutting before logging, marking of trees for directional felling, planning and aligning roads and skid trails according to the distribution of trees and the terrain, and halting harvest operation during rainy periods. On steep slopes, tractors are replaced with a skyline yarding system. With the Sabah-GTZ skyline system, machine movements on the ground and skid trail construction are unnecessary, which helps to reduce logging damage to a minimum (Chai, 1997). Areas with low stocking of commercially valuable species are surveyed for regeneration and rehabilitated accordingly. Commercial species that are overgrown by climbing bamboo and pioneer species are released to enhance their growth performance. The silvicultural strategy for managing logged-over forest allows sufficient flexibility in the selection of silvicultural operations as long as they remain within the principles of sustainable forest management.

The primary goal of the harvesting practice is to reduce logging damage by adopting best management practices (Kugan and Kollert, 1996). In the past, uncontrolled logging using the chainsaw and bulldozer system has left behind high levels of damage to the forest vegetation and soils. In harvesting 8 to 12 trees ha^{-1}, which is equivalent to 80-150 m^3 ha^{-1}, approximately 40-70 % of the residual forest is damaged (e.g. Fox, 1968; Sabah Forestry Department, 1989), and 17-30 % of the logging area is left as open spaces (Nicholson, 1979: Marsh *et. al.,* 1996). Although the higher logging damage in Sabah compared with elsewhere (e.g. in Suriname, Jonkers, 1987) is, in part, due to the higher extraction yield per hectare (over 80 m^3 ha^{-1}) and the larger size of the extracted tree (greater than 60 cm DBH; Fox, 1968), the main reason is that conventional logging practice in Sabah lacks the important elements generally prescribed in reduced impact-harvesting systems. For example, tree marking and stock mapping are not practised in conventional logging in Sabah even though these are important for planning the skidding network in relation to tree distribution. Also, directional felling is executed but with little regard to damage of future crop trees. In addition, skid trails are not pre-marked although it is necessary to restrict tractor movements during skidding operations. Furthermore, climber cutting to reduce vine tangles is not implemented.

The Sabah Forestry Department's approach to bringing the 2.6 million ha commercial forest into a well managed condition is to develop these forest management practices through a pilot project and transfer these technologies to logging licensees in Sabah through a long-term licence agreement. Concurrent with this development, the Sabah Foundation was developing its own sustainable harvesting practice compatible with the aspirations of ITTO's 2000 target.

2.3. The Sabah Foundation

2.3.1. Formation and role

The Sabah Foundation, or Yayasan Sabah, is of special interest here because the present study was conducted within its forest concession. The Sabah Foundation was established by an enactment of the Sabah State Legislature in 1966 with the mission to improve the quality of life of the people in Sabah in the fields of education, welfare and health

(Hepburn, 1979). The Foundation is managed by a Board of Trustees with the Chairman being the Chief Minister of Sabah. To fund its social programmes, the State Government allocated timber land to the Sabah Foundation to generate income. In 1970, the role of the Sabah Foundation was expanded to enable it to carry out economic, industrial and commercial development projects. In line with this expanded role, the Cabinet approved an increase of the forest concession to 854,700 ha and a 100-year licence agreement for timber was given. This area was scattered over various parts of the State, which encumbers timber harvesting planning and control. In 1984, the forest concession was further expanded and consolidated into a single block of 972,800 ha (about one eighth of the land area of Sabah) to be managed on a sustainable basis on a 60-year rotation as provided in the Sabah Foundation Forest Management Plan (1984-2032). The basis for the 60-year rotation was that dipterocarp forests could yield 2.0 to 4.6 m^3 ha^{-1} per annum (Tagudar and Reyes, 1960; Wan Razali, 1989), and at the lower end of this range production would be at least 120 m^3 ha^{-1} in 60 years.

2.3.2. The forest concession

The Sabah Foundation's forest concession is located in south-eastern Sabah occupying about 13 % of the total land area of Sabah (Figure 2.2). The concession is bounded by the Kinabatangan and Ulu Segama river in the north that drain in a north-east direction (ICSB, 1988). The eastern, western and southern concession boundaries follow natural ridges.

Within the forest concession, there are seven forest reserves of Class II status available for commercial utilisation. The present study involves two of the reserves, namely the Ulu Segama and Kalabakan Forest Reserves. The description of these reserves is given in section 2.4. In terms of land utilisation, only 82 % of the total forest concession is classified as productive forest. Ten percent of the total forest reserve is considered unproductive being inaccessible or containing non-commercial timber. Another 8 % was set aside as conservation areas. One of the conservation areas, Danum Valley Conservation Area totalling about 44,000 ha, was upgraded to Class I Protection forest in 1996.

The general topography of the forest concession varies with many rugged mountainous areas in the western, central and eastern parts. Situated between these mountain ranges are some wide valleys with lowland areas of peneplains and flood plains. These areas are mainly located towards the northern part of the forest concession along the Kinabatangan River and Segama River. Geologically, the parent material consists of sedimentary rocks, igneous rocks and crystalline basement. These rocks are composed of interbedded sandsone, mudstone and shale, with scattered occurrences of limestone.

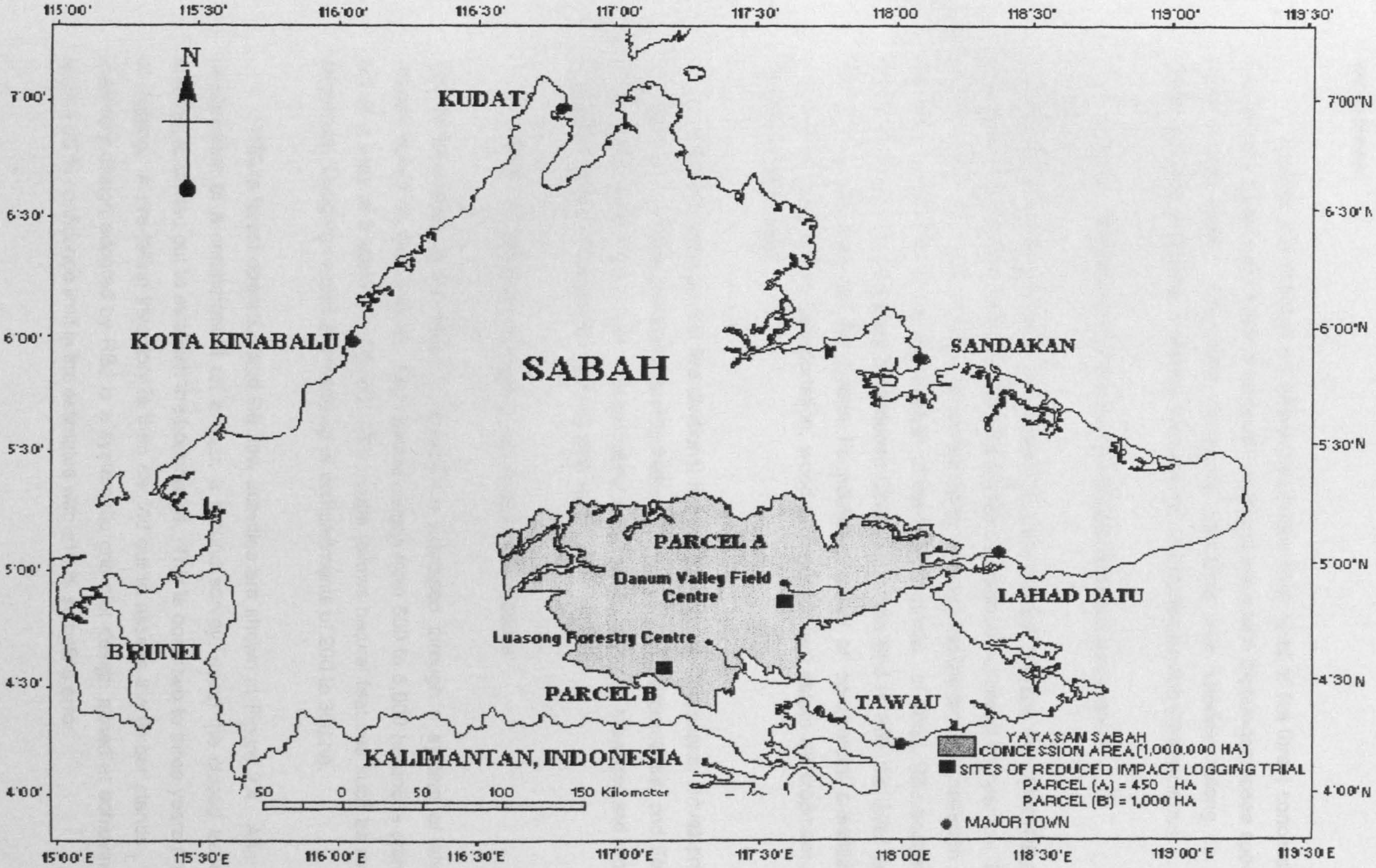


Figure 2.2 Map showing the Sabah Foundation's forest concession and RIL Project sites (Parcel A and B)

The areas with good soils, i.e. alluvium, sandy loams and clay loams, are confined mainly to the lowland areas. Soils derived from sandstone, mudstone and shale are found in steep areas.

Tropical rain forest is the natural vegetation over most of the forest concession. The lowland dipterocarp forest is generally heterogeneous with Dipterocarpaceae species being predominant. The most commonly occurring tree species belong to the Dipterocarpaceae genera of *Shorea*, *Parashorea*, *Dryobalanops* and *Dipterocarpus*.

2.3.3. Management of the Sabah Foundation forest concession

The management of the forest concession is under Rakyat Berjaya Sdn Bhd (RBJ), a wholly-owned forestry subsidiary within the Sabah Foundation's group of companies. RBJ in return pays the Sabah Foundation timber rights (fees) to log the forest concession and the fees are amortised over the duration of the licence period. In 1988, RBJ became a wholly-owned forest subsidiary of Innoprise Corporation Sdn Bhd (ICSB), the latter being the holding company for the Sabah Foundation's group of commercial subsidiaries involved in forestry, sea transportation, wood processing, real estate development and tourism (ICSB, 1996).

RBJ is organised into five divisions, namely the Forest Operations, Development and Research, Forest Rehabilitation/Plantation, Conservation/Environmental, and Forest Security Divisions (Figure 2.3). The company is headed by a Group Manager and reports to the RBJ Board of Directors. RBJ has 600 staff.

2.3.4. Conventional logging techniques and practices

Timber harvesting in the forest concession is managed through a system of annual coupes based on area control. Each coupe ranges from 600 to 5,000 ha and is planned out on a map at a scale of 1:50,000. The coupe follows natural features such as rivers, ridges etc. Logging coupes are made up of compartments of 200 to 300 ha.

RBJ's forest operation and log flow activities are shown in Figure 2.4. After the demarcation of a compartment on a map, a ground survey, using the closed traverse method, is carried out to establish the boundaries. This is done two to three years ahead of logging. A pre-felling inventory is then carried out to assess the timber stands. The inventory design adopted by RBJ is a systematic grid plot design aimed at achieving at least a 95 % confidence limit in the estimates with ±10 % sampling error.

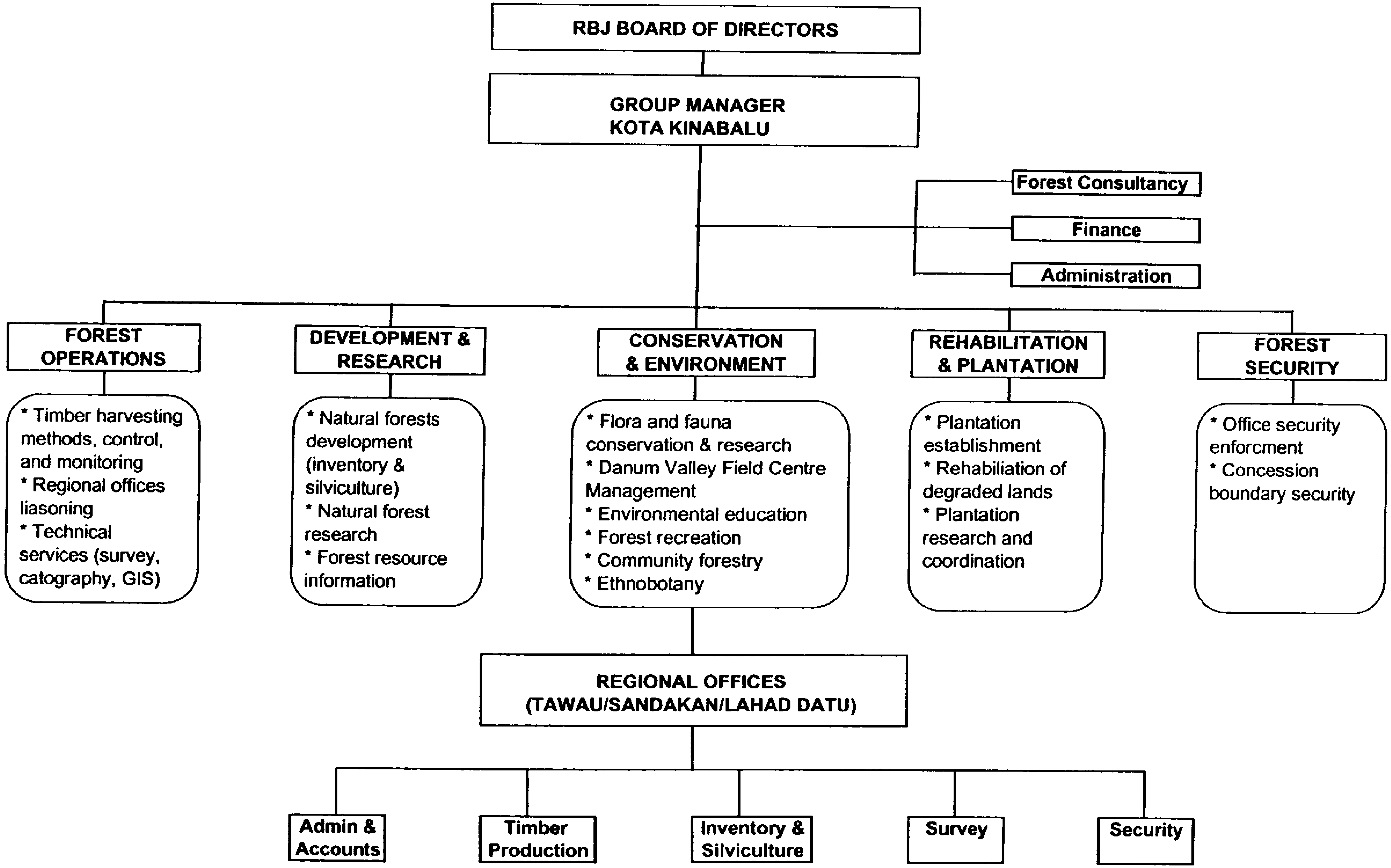


Figure 2.3 Organisation chart of Rakyat Berjaya (RBJ) Sdn. Bhd

LOCATION	ACTIVITY	TIMING	DESCRIPTION
FOREST	MAPPING	F-12 to 24	• Identify logging coupe and plan road network for the forest area on topographic map at scale 1 50 000
	SURVEY	F-12 to 24	• Survey coupe boundaries following natural features
	INVENTORY	F-12 to 24	• Conduct pre-felling inventory using systematic plot design
	ROAD CONSTRUCTION	F-12	• Logging contractor starts road construction based on field reconnaissance, alignment and demarcation of the roads upon receipt of approval from authorities
	FELLING	F	• Prior to felling, the logging contractor opens up the skid trails based on field reconnaissance of the area
	SKIDDING	F+1 to 6	• Extraction begins and logs are removed from the stump to log landings
LOG LANDING	LOG TREATMENT	F+ <1	• Logs arrived at the log landings are debarked, numbered, scaled, identified to species and assigned quality grade
	TRUCKING	F+<1	• Logs at the log landing are trucked to dumping point
DUMPING POINT	RAFTING	F+1 to 3	• Logs arrived at the dumping point are rafted and recorded
	TOWING	F+1 to 3	• Log rafts are towed to the log pond by motor launches
LOG POND	SCALING	F+1 to 3	• At the log pond, logs are scaled for royalty payment and sorted into rafts based on shipment specifications
	BUYER/SELLER INSPECTION	F+1 to 3	• Buyer and seller conduct a joint inspection of rafted logs to agree on log grades
	SALE	F+1 to 3	• Log consignment is removed from the log pond to shipside

Figure 2 4 RBJ's forest operation log flow and activities

Prior to the felling operation, RBJ applies to the Forestry Department for issuance of a coupe permit by attaching a map showing the location and alignment of roads as well as the inventory estimates RBJ employs logging contractors to execute the logging operation They are paid on the basis of logs delivered. The contractor is responsible for constructing the main and secondary roads according to the specifications and alignment marked out by RBJ This excludes skid trails which are left to the contractor's discretion.

Following road construction, the logging contractor starts felling and skidding operations Felling of trees is done with chainsaws equipped with a 60-70 cm guide bar. The most commonly used chainsaw is the Stihl 070 with a capacity of 7 hp which weight about 13 kg The extraction of logs from the forests to log collection points or landings is done with bulldozers, usually the Caterpillar D7 or Komatsu D85. The former weighs about 27 tonnes with an engine capacity of 215 hp, whilst the latter weighs 19 tonnes and has a 215 hp engine Both bulldozers are equipped with a dozer-blade and a winch. This system is referred to as the conventional logging system for the purpose of this thesis.

Logs that are skidded out from the stump are usually collected at roadside or log landings Each contractor establishes their own log landings ranging in size, but not more than 0 5 ha, at various places in the coupe. At the log landing, logs are debarked, numbered, identified to species, and their diameter and length are measured for calculation of wood volume They are also each assigned a quality grade according to the Sabah Log Grading Rules (Sabah Forestry Department, 1980). Logs are then loaded onto trucks using mechanised log loaders and hauled to dumping points. At the dumping points, the logs are sorted by species and dumped into the river where they are rafted. Log rafts are then towed to the log ponds waiting to be despatched to the respective buyers.

When all logs have been removed from a coupe, RBJ notifies the Forestry Department for a closing coupe inspection Once the Forestry Department is satisfied that the regulations have been adhered to, the coupe is closed for further logging

Following closure of a coupe, RBJ conducts a 5 % (by area) diagnostic regeneration sampling of the logged-over forest at five to ten years interval. The aim of this exercise is to determine areas suitable for silvicultural treatments to promote growth of the future crop

2.3.5. Log production and revenue

Since 1971, RBJ's log production had increased from a low of 287,000 m^3 to slightly more than one million cubic metres by 1974 (Figure 2.5). Production then surpassed the one million m^3 mark peaking at about three million m^3 in 1992. Then the annual production level fell to about 1.5 million m^3 in 1994. The increased production over the years is related to the increase in the annual allowable cut as well as improvement in harvest yield. Average log extraction yield ranges from 70 to 166 m^3 ha^{-1} (Marsh and Greers, 1991). The wide range of extraction yields was associated with variation in the stocking density of large commercial trees, terrain variability and differences in logging practices among logging contractors.

The main species groups harvested from the forest concession comprised *Shorea* spp. (70 %); *Dryobalanops* spp. (10-20 %) and the remainder were *Dipterocarpus* spp. About 70 % of the logs quality were above the Sawmill Quality (SQ) grade (see Appendix 2.2 for information on the Sabah Log Grading Rules).

Sales of wood products contributed about 90 % of the total revenue of ICSB. For example, in 1995 the revenue generated from timber products was RM119 million comprising 85 % of the total turnover of ICSB at RM140 million.

2.4. The Reduced Impact Logging (RIL) Project

ICSB undertakes collaborative ventures through its forestry subsidiary RBJ with local and international institutes to strengthen its management and conservation efforts. One such collaborative project involves the improvement of harvesting techniques to reduce impact on the forest. This commercial venture is known as the Reduced Impact Logging (RIL) Project, and is of relevance to this study because its investigation of the economics of improved harvesting systems uses this project as a case study.

2.4.1. Project partners

The RIL project is a joint venture between ICSB and New England Electrical Systems (NEES). ICSB plays an active role in the RIL Project through its forestry subsidiary RBJ. NEES, on the other hand, is a public utility company engaged in the business of the generation, transmission and sale of electricity at the wholesale level in the states of Massachusetts, Rhode Island, New Hampshire and Vermont in the United States of America (USA).

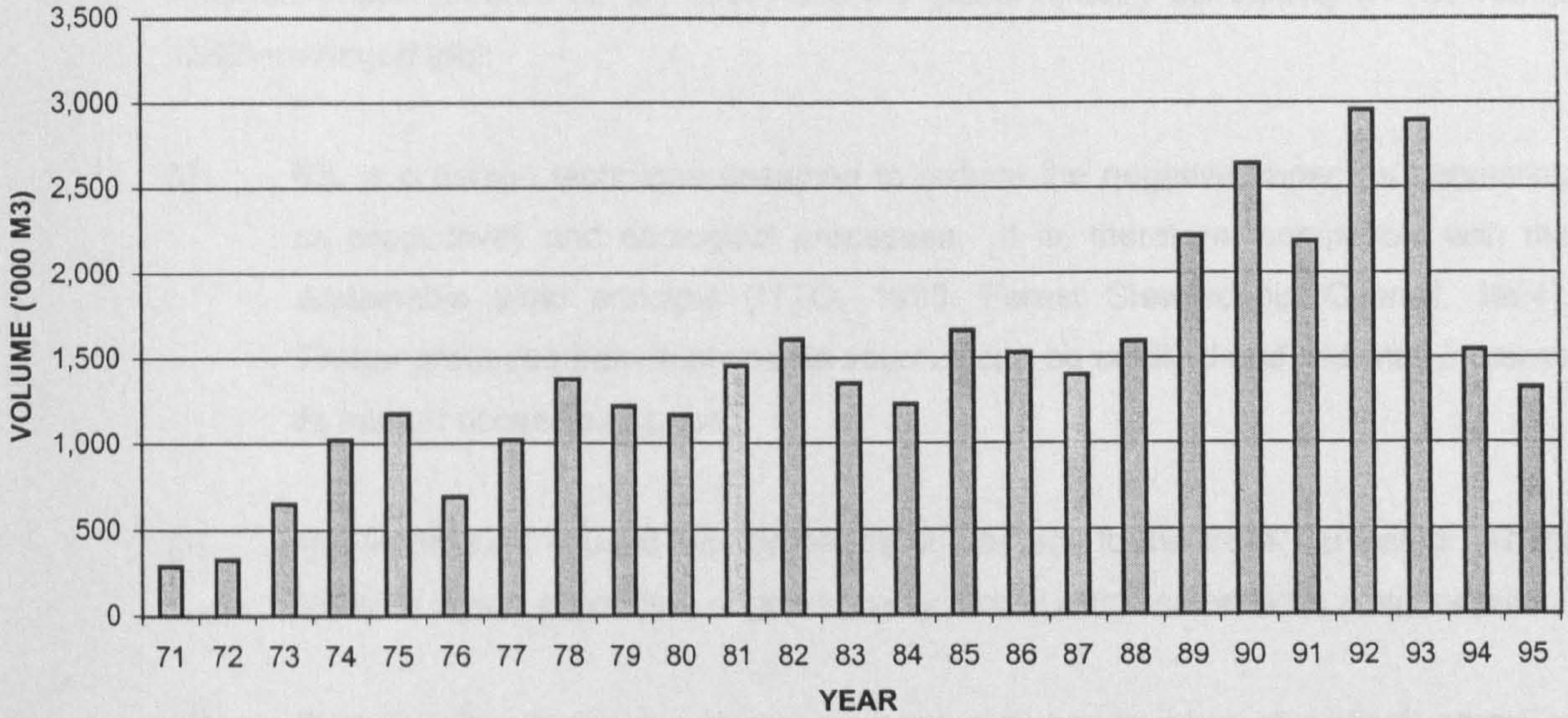


Figure 2.5 Log production from the Sabah Foundation's forest concession (1971-1995)

2.4.2. Rationale and objectives

The project started in 1992 and was designed to test the practicality of Reduced Impact Logging (RIL) techniques. ICSB/RBJ and NEES's enthusiasm for RIL techniques at that time was fully compatible with the mounting interest in sustainable forest practices by both local authorities (Udarbe *et. al.*, 1994) and the global forestry community (ITTO, 1990). ICSB envisaged that:

(i) RIL is a benign technique designed to reduce the negative impact of harvesting on productivity and ecological processes. It is, therefore, compatible with the sustainable yield principle (ITTO, 1990; Forest Stewardship Council, 1994). Timber produced from sustainable sources can be certified and this may increase its market access and price.

(ii) RIL techniques caused less breakage or wastage to the trees harvested. There will be a higher proportion of good quality timber which commands a higher price.

(iii) The reduction in logging damage leaves a higher number of residual stems of younger trees that will potentially form the crop at the next harvest, which means a higher yield and thus higher revenues from the future harvest.

(iv) Tropical timber is becoming a scarce resource as a result of deforestation, and uncontrolled harvesting practices and other mismanagement (Myers, 1989; Sedjo *et. al.*, 1992; FAO, 1993). All things being equal, the future price of tropical timber should increase above the inflation rate of most other commodities.

The two companies were brought together by a Los Angeles-based firm called COPEC, which has been developing links between USA utility companies and tropical forest produce companies in carbon-offset schemes.

Carbon-offset schemes have been initiated in the USA in response to the USA Climate Change Action Plan aimed at tackling threats of global warming (Anon., 1993). The Action Plan consists of almost 50 actions involving all sectors – industry, transportation, homes, office buildings, forestry and agriculture. These actions are targeted at specific sectors to stimulate markets for technologies that reduce emissions of carbon dioxide (CO_2), methane, nitrous oxide, and halogenated compounds that contribute to global warming. The most abundant atmospheric greenhouse gas by volume is carbon dioxide, which is released when vegetation or carbon-based fossil fuels are burnt. Under the US Energy Act (1992) a voluntary register has been established for investment activities by utility companies that may be considered allowable offsets against future tax liability. Anticipating these developments, NEES decided to seek a partner for a pilot CO_2–offset contract through changes in tropical forest management. NEES's preferred to use tropical forest because this forest contains a higher biomass and biodiversity than temperate forests, hence, it is a better sink for carbon sequestration in photosynthesis.

There are two options available for NEES to venture into carbon-offset schemes in the tropics. The first is planting trees and the second is altering management systems. NEES chose the second option because it was believed to give immediate impact and to be less expensive.

2.4.3. RIL techniques

The project aims to achieve its objectives by harvesting trees according to a set of benign harvesting techniques and guidelines. These techniques are old concepts with a new role and were initially drafted from best management practices recommended by the Queensland Forest Service (Australia) and the Rainforest Alliance's Smartwood certification program (Pinard *et. al.,* 1995). They comprise the following elements:

- Climber cutting of large woody lianas 9 to 12 months prior to harvesting aimed at destroying the canopy liane network so that felled trees will not drag other trees down with them and cause incidental damage (e.g. Fox, 1968; Liew, 1973; Appanah and Putz, 1984)
- Planning of roads and skid trails on a map scale of 1:5,000 with special reference to minimising incidental disturbance to soil, streams and vegetation
- Planning of log landings with reference to their size and location to reduce unnecessary openings and soil disturbance
- Numbering and mapping of all harvestable trees for the purpose of planning skid routes and for post-harvest audit of trees
- Main roads built with consideration of minimising soil erosion
- Skid trails flagged on the ground to restrict tractor movement during trail construction and skidding
- Skid trail density kept to a low intensity not exceeding 150 m ha^{-1} in order to reduce unnecessary vegetation and soil damage
- Directional felling to align trees towards skid trails and away from potential crop trees to reduce damage (e.g. Marn *et. al.,* 1981; Hendrison, 1990)
- Bulldozer operators winch logs out of felling areas instead of driving the bulldozers to the stumps to collect fallen logs

- Closing-down operations carried out when logging is completed in a logging unit. The activities include removing obstructions to streams and draining skid trails at intervals according to their slope
- Setting aside of buffer zones (in addition to riparian reserves) along streams (e.g. Cassells, 1992).

2.4.4. Project area

The RIL Project area is located within the Sabah Foundation forest concession and comprises 1,415 ha that is divided into two parcels situated in different administrative districts (Figure 2.2). Parcel A of 450 ha is within the Ulu Segama Forest Reserve in Lahad Datu District (5° 0'N, 117° 30'E, 150-750 m.a.s.l). It is accessible by road either directly from Lahad Datu (90 km) or via the Danum Valley Field Centre (40 km). Parcel B contains 985 ha and is within the Kalabakan Forest Reserve (KFR) in Tawau District (4° 25'N, 119° 29'E, 150-900 m.a.s.l.). It is accessible from Tawau via the Luasong Forestry Field Centre (LFC). The distance by road from Tawau to LFC is approximately 160 km and from LFC to Parcel B is approximately 80 km. The two parcels were planned to be logged within three years starting July 1992.

2.4.5. Research and development

The pilot project has a research programme to quantify the carbon savings of RIL compared with conventional harvesting. This work is crucial since funding is based on carbon-saved by using the RIL techniques. The University of Florida in collaboration with ICSB heads this research programme. The research methods have been described by Putz and Pinard (1993) and in Chapter 3 and 4 of this thesis. The present study utilises the research data collected under this research program to facilitate the economic analysis.

2.4.6. Environmental Audit Committee (EAC)

To ensure compliance of practice in the field with the RIL guidelines, a three-member Environmental Audit Committee conducted thorough site inspections three to five times during the contract. The Environmental Audit Committee comprises representatives from the Forest Research Institute of Malaysia (FRIM), the USA-based Rainforest Alliance, and the University of Florida, Gainesville.

2.4.7. Investment

The total investment for the RIL project is approximately US$450,000 for three years, and is borne by NEES in return for a share of the carbon credits from carbon sequestrated in the forest biomass. The investment covers only the costs of carrying out the RIL activities as outlined above.

2.5. Study sites and environment

The major part of the fieldwork for this study was conducted within one part of the Ulu Segama Forest Reserve (USFR) which has a total area of approximately 252,000 ha. The timber, carbon, soil and rattan study was sited within Parcel A (450 ha) of USFR. The experimental sites for the hydrological and wildlife studies were located outside Parcel A but still within the USFR. A minor study on felling and skidding time and motion were conducted outside the USFR in Parcel B in the Kalabakan Forest Reserve (KFR) which has a total area of approximately 136,000 ha.

The different field sites chosen for this study were dictated by a tight work schedule due to the commercial nature of the RIL project. Secondly, the main research interest of the RIL Project (timber, carbon and soil values) was expanded to include hydrological and wildlife interests. This expansion of research scope was made after the RIL Project had commenced. At that instant, the logging operation in Parcel A had started, and pre-logging values for the additional hydrological and wildlife values could not be established. Hence, the alternative was to use secondary information for the two values. For the same reason, the felling and skidding time-motion study was conducted in Parcel B where logging using RIL techniques commenced only a year later, instead of Parcel A.

2.5.1. Site description for the timber, carbon, soil and rattan study

2.5.1.1. Location, size and relief

Parcel A of 450 ha is within part of coupe YL2/93. The coupe is approximately 2,000 ha and is bounded by the *Segama* River to the west and steep hills to the east and north. The Segama River is approximately 50 m wide. To the south, the relief is relatively less hilly but broken ridges persist. The coupe is divided into 43 logging units or compartments of more or less 50 ha each, and eight of the 43 logging units made up Parcel A (Figure 2.6). Within Parcel A, the relief is hilly characterized by broken ridges and the altitude ranges from 100 m to 1,200 m asl. The relief creates numerous creeks and streams

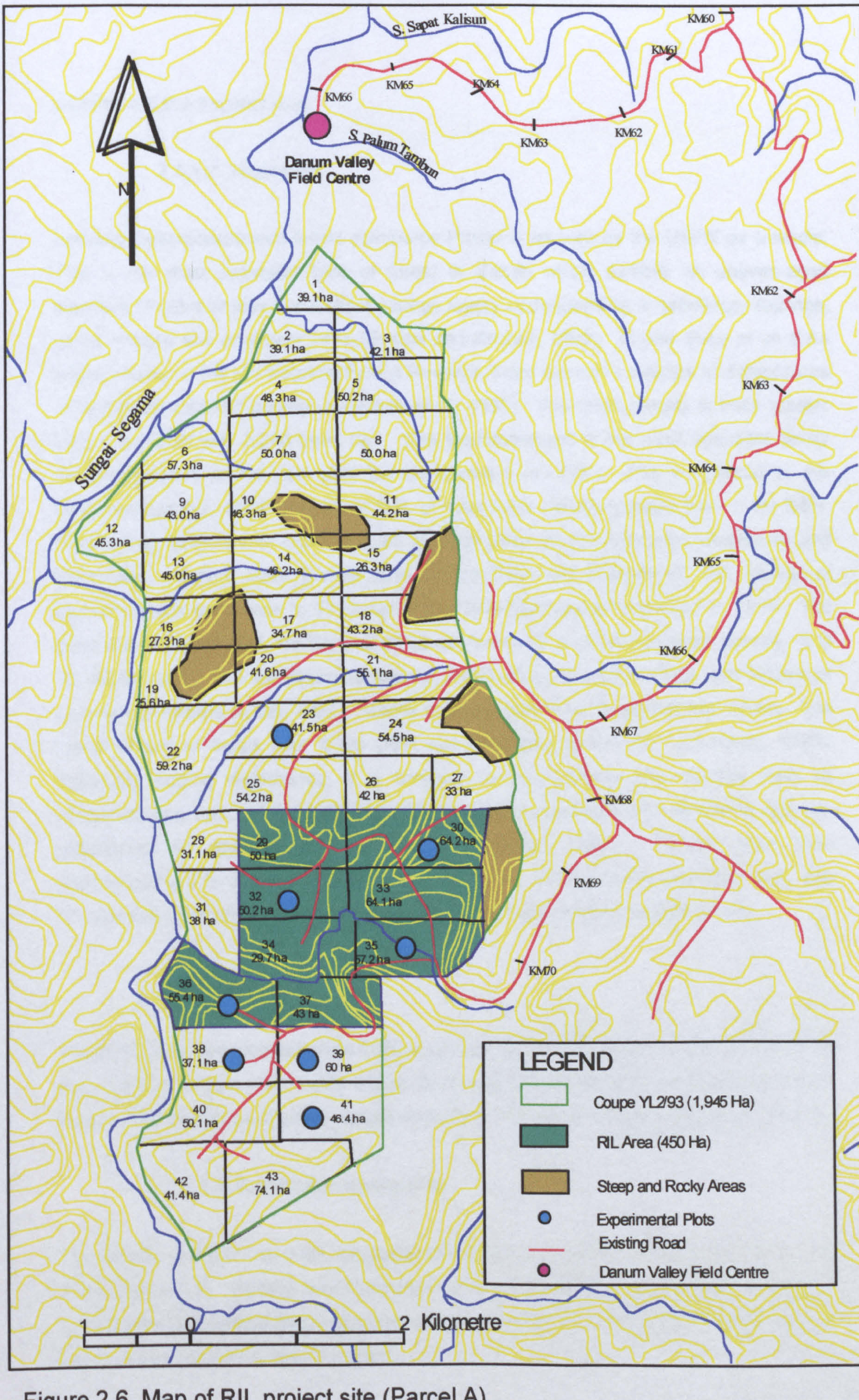


Figure 2.6 Map of RIL project site (Parcel A)

draining into the *Segama* river.

2.5.1.2. Vegetation

Lowland Dipterocarpaceae forest dominates Parcel A as well as the USFR as a whole. This is the most extensive type of forest in Sabah which exhibits an uneven-aged structure of more or less five distinct canopy layers corresponding to seedlings, saplings, poles, mature and emergent trees (Bossel and Krieger, 1990). In one study of an 8 ha primary forest in the Ulu Segama Forest Reserve, there were 511 species of dipterocarps in 59 families and 164 genera (Newberry *et al.*, 1992). The mean density of trees greater than 1 cm DBH was 2,248 trees ha^{-1}. The Euphorbiaceae is the most abundant family comprising 28 % of the total stem density above 1 cm DBH. This is followed by the Dipterocarpaceae, which comprises 9 % of total stem density greater than 1 cm DBH. Three other families with high densities of small trees are Annonaceae, Lauraceae and Meliaceae. If only trees greater than 10 cm DBH are considered, the density of Euphorbiaceae decreases to 21 % while the Dipterocarpaceae increases to 16 %. For trees above 30 cm DBH, the Dipterocarpaceae forms 43 % of the total stem density. It is not uncommon to find the Dipterocarpaceae contributing 70 to 80 % of the total volume of commercial timbers (ICSB, 1995). Lianes are also commonly found in these forests. The mean density of lianes over 2 cm DBH was estimated at 881 ha^{-1} (Campbell, 1990). Following logging disturbance, it is common to find pioneer tree species such as *Anthocephalus* spp., *Macaranga* spp., *Endospermum peltatum* and *Neonacla* spp. re-established on open areas (Howlett and Davidson, 1996). Pioneer trees form approximately 3 % of trees greater than 1 cm DBH. Vines (mainly *Merremia* spp., and *Uncaria* spp.) and climbing bamboo (*Dinochloa* spp.) also thrive in logged forests.

2.5.1.3. Land use

The USFR has been logged since 1970 in annual coupes of between 2,000 and 5,000 ha over the last 20 years to provide timber for a large integrated timber mill at Lahad Datu, Sabah. The extraction intensity ranges from 73 to 116 m^3 ha^{-1} (Marsh and Greer, 1991).

2.5.1.4. Rainfall and temperature

The climate of USFR has been measured at the Danum Valley Field Centre (DVFC) since 1986 (Figure 2.7). Rainfall was measured using a *Casella* tilting siphon rainfall recorder. Air humidity and temperature were measured using dry and wet bulb thermometers and maximum and minimum thermometers.

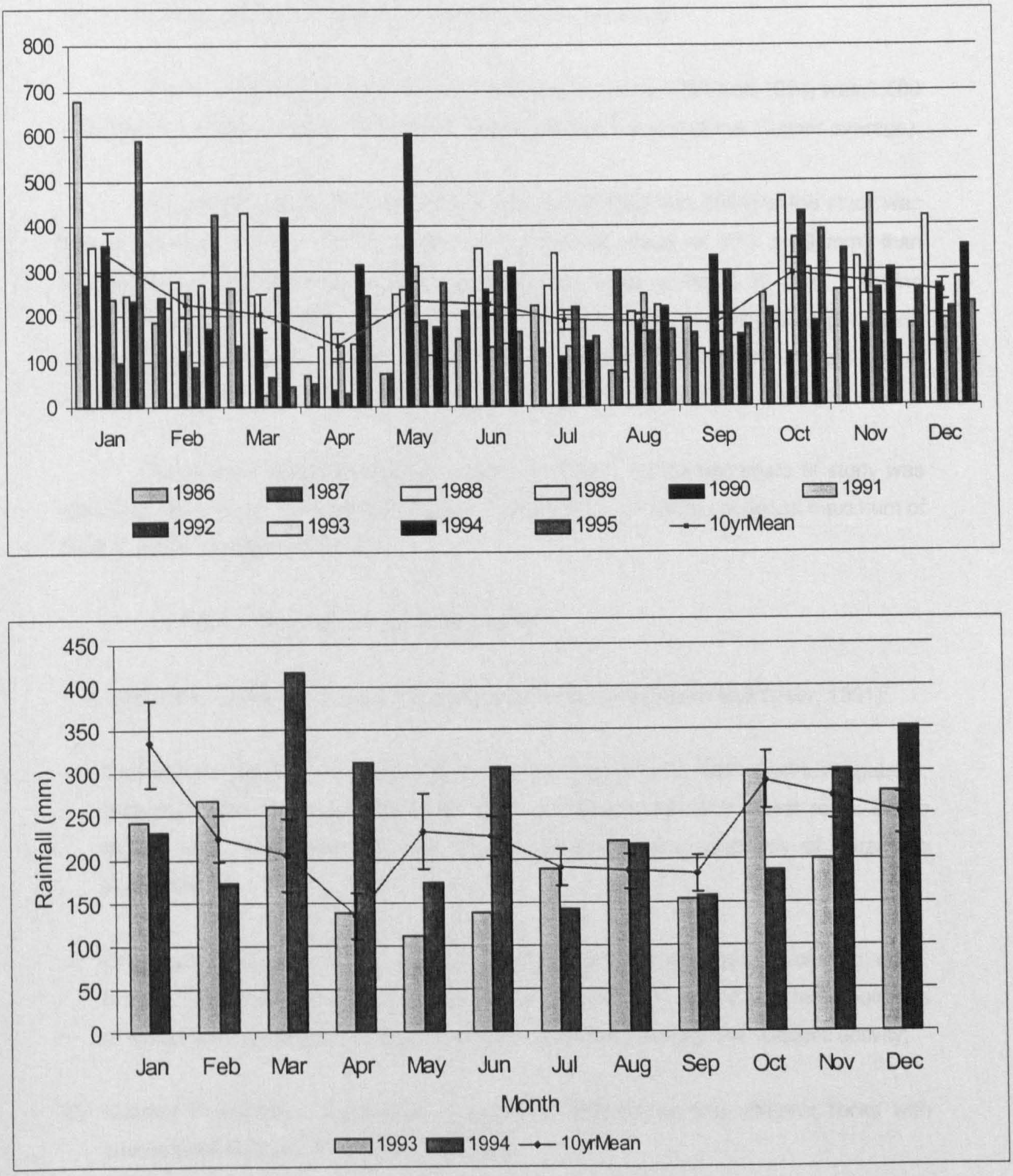


Figure 2.7 Annual rainfall pattern at Danum Valley Field Center over a 10-year period (top frame) and during the two years of the experiment (bottom frame).

The mean annual rainfall at DVFC over 10 years (1986-1995) is 2,727 ± 83 (SD) mm. There are generally two slightly wetter periods in the year with the influence of the wetter north-east monsoon that starts in October until February, and the south-western monsoon between May and September. April is the driest month of the year. However, the rainfall distribution can clearly be classified as non-seasonal.

Total annual rainfall during the experimentation years, 1993 and 1994, was 2,500 ± 18 mm and 2,966 ± 26 mm, respectively (slightly below and above the 10-year average).

The general pattern of rainfall for the two years (1993 and 1994) of the study was higher between October and February (with a monthly mean of 275 ± 19 mm) than between March to September (which had a monthly mean of 193 ± 12 mm). During 1993, more rain was received than the respective 10-year monthly average during February, March, August, October and December. In 1994, rainfall in March, April, June, August, November and December was greater than the 10-year monthly average.

The mean annual temperature recorded at DVFC for the two years of study was consistent with the ten-year period (1986 to 1994) at 26.7° C with an absolute maximum of 30.9° C and a minimum of 22.5° C.

2.5.1.5. Geology, soil and topography

The USFR was formed by three major geological formations (Marsh and Greer, 1991):

i) Crystalline basement - a group of igneous and metamorphic rocks (including gabbro, dolerite, diorite and metamorphosed forms of these rocks), the oldest rocks in the region, with locally very diverse lithologies and including outcrops of ultramafic serpentine;

ii) Chert-Spillite Formation - a mixture of many different lithologies including chert, breccia, agglomerate, spillite keratophyre, basalt, pillow lava and tuff, most outcrops of which have undergone disturbance due to slumping, faulting and volcanic activity;

iii) Kuamut Formation - a melange of slumped sedimentary and volcanic rocks with interbedded sandstone, mudstone and tuffs.

The combination of these lithologies gave rise to soils mainly of the Bang and Mentapok association. The majority of soils in the Bang association are developed over sandstone and mudstone occurring on steep hills of up to 300 m altitude with slopes averaging between 15° and 25°. The dominant soils are clay loam overlying clay (Acres *et. al.*, 1975).

2.5.2. Site description for the hydrological and wildlife study

These studies were conducted near Parcel A within the USFR. The general characteristics of the USFR have been described in an earlier section of this Chapter (Section 2.5.1). The hydrological data came from two earlier studies conducted by other researchers at the USFR. The first study was by Nussbaum (1995) and the second was by Douglas *et. al.* (1990). Similarly, the wildlife studies had been carried out by other workers within the USFR.

2.5.3. Site description for the felling and skidding time and motion study

2.5.3.1. Location, size and relief

This aspect of the study was conducted in Parcel B and its adjacent area within the KFR (Figure 2.8). Parcel B is coupe YT3/94 and comprises 985 ha divided into 18 compartments. Each compartment is about 55 ha. Parcel B is bounded by the *Anjeranjermut* river to the south, a permanent access road to the west, and steep ridges that are more pronounced to the east than the north. The geographical relief within Parcel B is similar to that found in Parcel A, which is hilly with broken ridges. The altitude ranges from 250 m to 700 m asl and generally has a westerly aspect. The whole coupe was logged using RIL techniques. Lying north and adjacent to Parcel B is coupe YT4/94 which contains 700 ha. This coupe was all logged by CL techniques and a felling and skidding time-motion study was also conducted in this coupe as a comparison with the results obtained in Parcel B.

2.5.3.2. Vegetation

The natural vegetation in coupes YT3/94 (Parcel B) and YT4/94, and within KFR generally, comprised mixed-age lowland Dipterocarpaceae forest. This forest extends to an altitude of 600-750 m. Dipterocarpaceae account for 60-90 % of the volume (Thomas *et.al.*, 1976). The *Shorea* species timber group is the most abundant accounting for 24-32 % of the commercial volume. Timber stocking for all trees 60 cm DBH and above is estimated at 140 m^3 ha^{-1} (ICSB, 1996b).

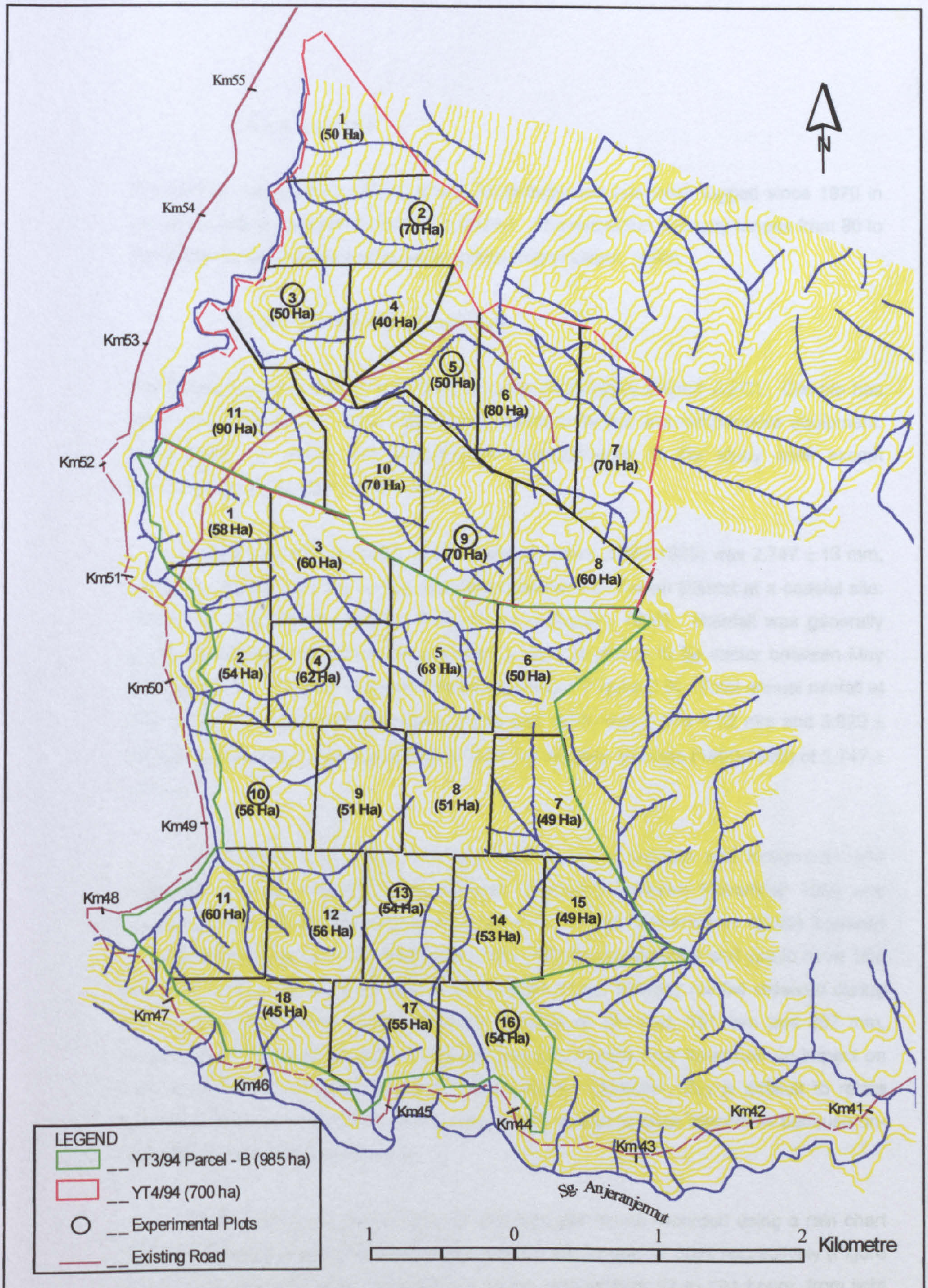


Figure 2.8 Map showing the RIL area (YT3/94) and CL area (YT4/94) where the felling and skidding time-motion was conducted at RIL project site Parcel B

2.5.3.3. Land use

The KFR is managed for natural timber production and has been logged since 1970 in annual coupes of between 2,000 and 5,000 ha. The extraction intensity ranges from 80 to 100 m^3 ha^{-1} using crawler tractor logging (Marsh and Greer, 1990).

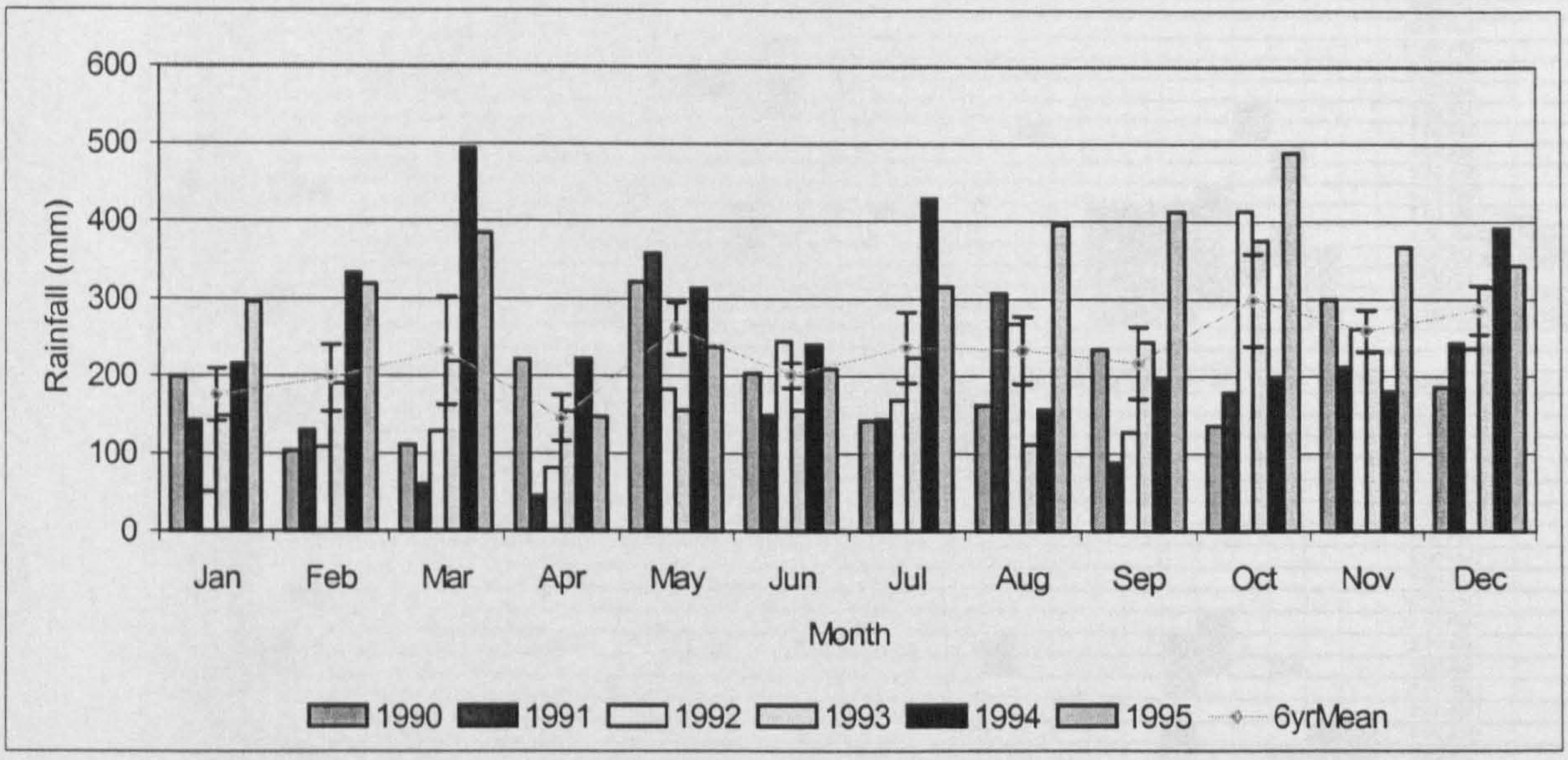
2.5.3.4. Rainfall and temperature

The nearest weather station is located at Luasong Forestry Center (LFC). Climate has been measured at LFC since 1990 using standard rainfall and temperature equipment. There were no rainfall and temperature measurements at the study sites except recordings of the number of rain-days.

The mean annual rainfall at LFC over six years (1990-1995) was 2,747 ± 13 mm, which was higher than the rainfall recorded elsewhere in Tawau District at a coastal site: 1,786 mm (1991-1995; Statistics Department of Sabah, 1996). Rainfall was generally evenly distributed throughout the year with a slight tendency to be wetter between May and December, and drier between February and April (Figure 2.9). Total annual rainfall at LFC during the experimentation years (1994 and 1995) was 3,374 ± 32 mm and 3,920 ± 27 mm, respectively, significantly higher than the six-year average (1990-1995) of 2,747 ± 13 mm.

The felling time-motion study was carried out in October and November 1994 while the skidding time-motion study was conducted between November 1994 and January 1995. Based on rainfall received at LFC, the difference in rainfall between October 1994 (199 mm) and November 1994 (180 mm) was small and would have little influence on the results of the felling time-motion study. Monthly rainfall received during the skidding time-motion study was more variable at 180 mm, 391 mm and 297 mm, respectively. The high variation in rainfall between months may have had an impact on the results of the skidding time and motion study. However, this is difficult to relate directly to the results of the time and motion study except to draw inferences because on-site rainfall data was not available.

At the study site, the number of rain-days per month recorded using a rain chart between September and December 1994 was 18, 19, 15 and 17 days respectively (Figure 2.10). The total rain-hours received in a month ranged from 52 to 101 hours, from light showers to heavy downpours. December 1994 was a wetter month than September, October and November 1994.



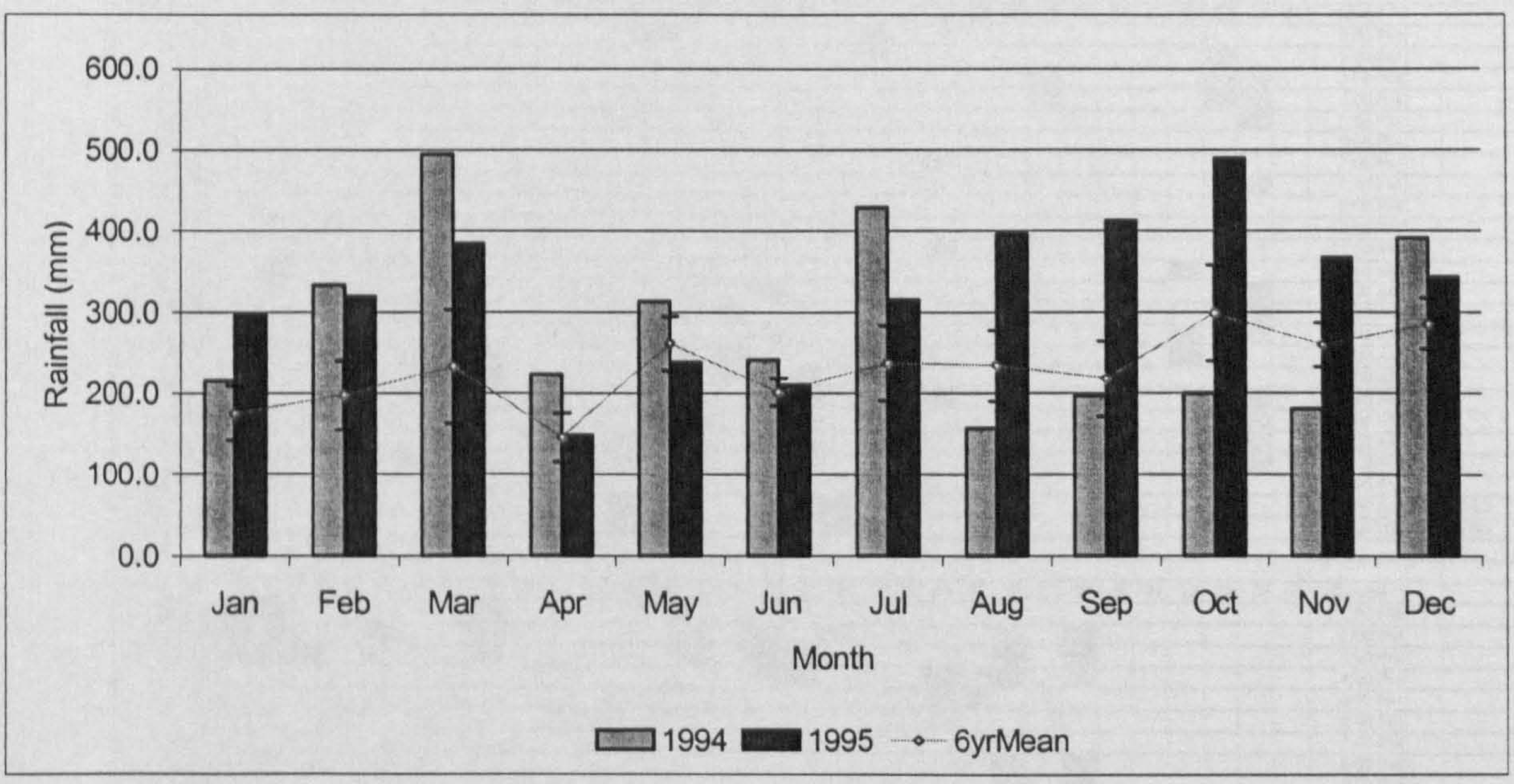


Figure 2.9 Annual rainfall pattern at Luasong Forestry Center for a 6-year period (top frame) and during the two years of the experiment (bottom frame).

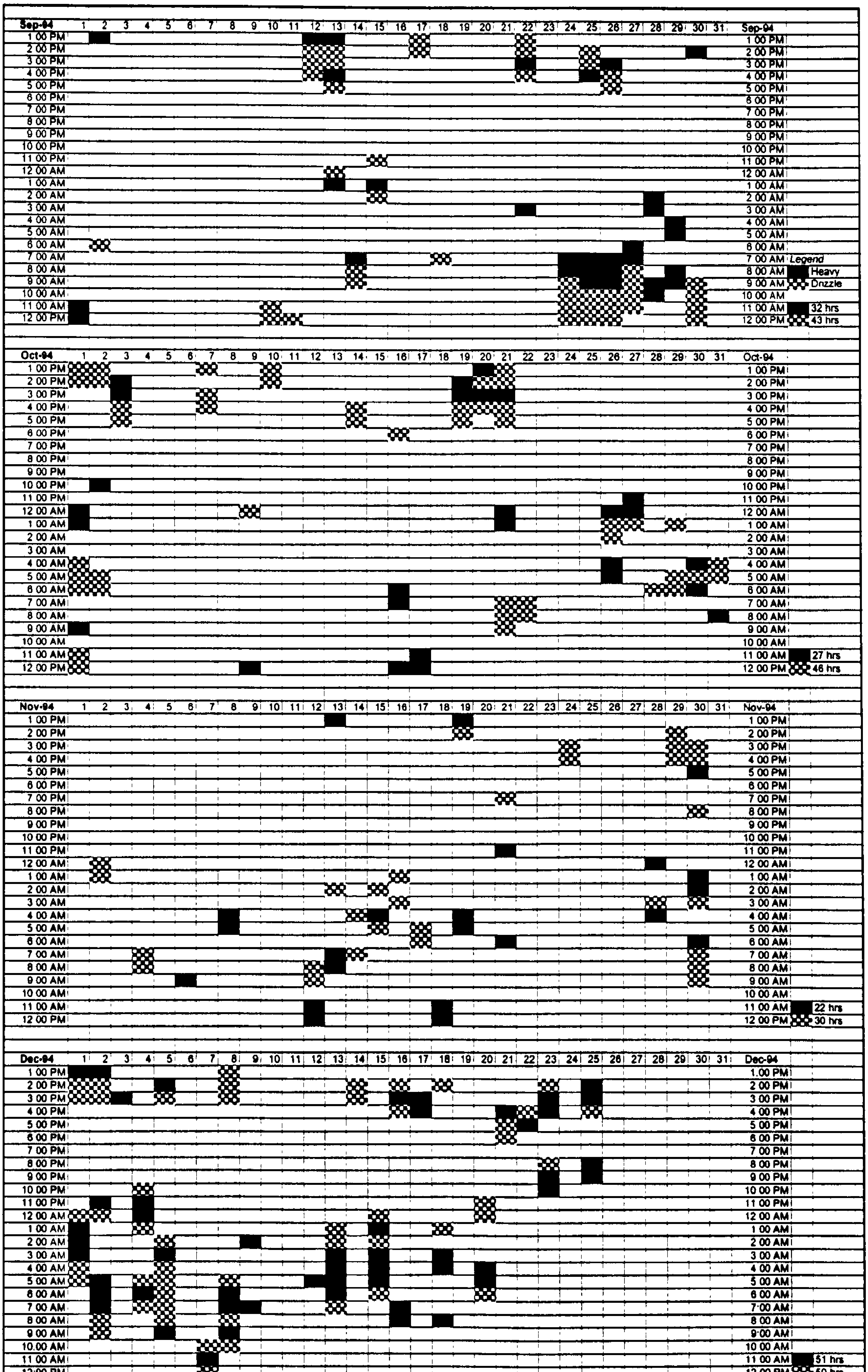


Figure 2.10 Rain-days chart recorded in Parcel B from September to December 1994 (heavy rain are shown in black and drizzle in hatched). Monthly totals for each of these two rainfall types are shown on the right of the figure.

Mean annual temperatures recorded at LFC for the years 1994 and 1995 were 30° C and 31° C, respectively. This is consistent with the six-year mean (1990 to 1995) recorded in Tawau of 31° C and a maximum of 31.5° C and minimum of 24.1° C.

2.5.3.5. Geology, Soil and topography

Parcel B falls under the Maliau Association that occurs on sandstone with minor inclusions of mudstone (Wright, 1975). The sandstone is siliceous, hard and greyish. The mudstones are generally grey or black and are carbonaceous. This group of parent materials gives rise to soils of the Orthic Acrisols of the Kapilit and Tanjong Lipat families that are commonly found on the dip slopes. They also occur on scarp slopes where Dystric Cambisols of the Antulai family are dominant. Gleyic Podzols of the Pa Sia family occur in small areas.

2.6. Summary

Forestry is an important sector in the economy of Sabah and for the past two decades it has been the highest revenue earner. Although the sector has shown a decline in revenue contribution in the last four years, it will continue to have a large impact on the economy of Sabah given that 45 %, or 2.5 million ha, of the total land area of Sabah is occupied by forest reserves. Logged forests, rather than primary forests, will play an increasing role in the future. The importance of the future role of forestry in Sabah's economy is reflected in the Forestry Department's recent initiative in developing a management system that would sustain timber production in its 2.5 million ha of commercial forest (Kleine and Heuveldop, 1993). An important aspect of Sabah's forest management system is to improve conventional harvesting techniques to reduce logging damage to vegetation and soil. Concurrent with this development, Innoprise Corporation Sdn Bhd (ICSB) initiated a reduced-impact logging (RIL) project with a similar objective of reducing logging damage but recognising forests as a carbon sink. This RIL project is the subject of this thesis and the study area is located within one part of the one million ha forest concession. The forest concession of ICSB constitutes approximately 10 % of the total land area of Sabah, and contains most of the forest types that are found in the forest reserves. Thus, ICSB is the largest timber producing company in Sabah with annual production output of 1.0-2.0 million cubic metres of logs. The introduction of RIL practices that incorporates additional forest planning activities and climber cutting, 100 % tree inventory and mapping, skid trail mapping etc. incurs additional costs. This has financial as well as economic implications for ICSB. This is the primary context of this research and the overall aim is to establish the economic costs of RIL incorporating both timber and non-timber benefits. The economic cost of RIL is relevant and of interest to policy- and decision-makers from the private and public sectors because it affects the company's "bottom-line". Also, the successful expansion of RIL to a wider area hinges upon what it costs. The purpose of this research is to shed some light on this aspect of reduced-impact logging that is an important instrument to achieve sustainability of timber production in tropical forests.

Chapter 3: Methodology

3.1. Framework of economic analysis

The framework of the economic analysis is shown in Figure 3.1 and comprises three parts; firstly the identification and description of the harvesting methods (experimental treatments); secondly, the ecological impact assessments of the various values arising from harvesting impacts, and thirdly the economic benefit-cost analysis.

3.1.1. The experimental treatments

The experimental treatment for the study is the reduced impact logging (RIL) and conventional logging (CL) techniques. RIL is analogous to the generic "supervised" or planned logging, and CL is "unsupervised" or unplanned logging (e.g. Marn and Jonkers, 1981). The salient features and differences between RIL and CL techniques are given in Table 3.1.

3.1.2. Ecological impact assessments

The purpose of the ecological impact assessments is to assess the impact of logging and to provide the data inputs for the economic analysis. Primary and secondary data sources were used for this purpose. The former refers to original data collected from experimental plots in the study sites. The latter are sourced from published work. Primary data were collected for timber, carbon, soil and rattan values whereas secondary data were used for water and wildlife values. The reason for using secondary data is because logging had preceded the start of these research components.

The sampling objectives and designs for the primary data collection data are shown in Table 3.2. Further details of each experimental design are given in section 3.4 of this chapter. The experimental designs for the timber, carbon and soil studies were developed by the RIL Project team comprising research staff from ICSB (including myself) and the University of Florida, USA (Professor Jack Putz and Dr Michelle Pinard) with the latter as lead investigator. The experimental designs for the inventory of rattan and the felling and skidding time and motion studies were developed by me.

The data collection was scheduled at different periods as shown in Table 3.3, and depended on the logging schedule in Parcel A. For timber, carbon and soil values, data were collected pre- and post-logging. However, only post-logging data were

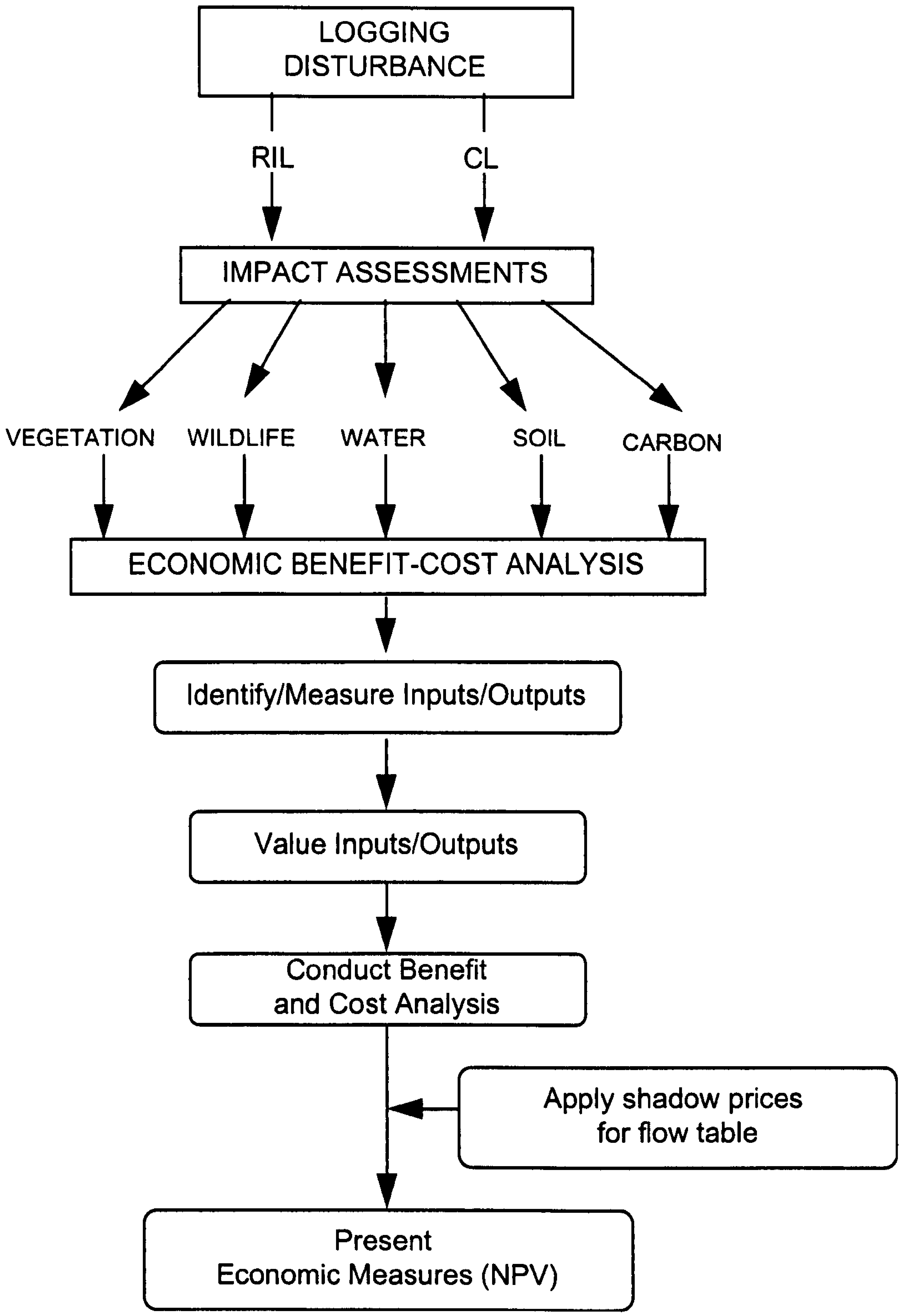


Figure 3.1 Framework of economic assessment

Table 3.1 Salient features and differences of harvesting components between RIL and CL techniques

Harvesting components	RIL	CL	RIL's difference
A Pre-harvest operations			
1 Boundary survey and mapping	√	√	• There is no difference between RIL and CL. In both cases, the logging coupes are surveyed and mapped
2 5 % pre-felling inventory	√	√	• Same as in CL practice; a pre-felling inventory is carried out to determine the timber stand and stock
3 Tree marking/locating	√	x	• Trees > 60 cm DBH are numbered and mapped on a map of 1:5000 to facilitate the alignment of skid trails and the location of trees/stumps; trees >20 cm DBH that may be damaged from felling or skidding are paint-marked
4 Climber cutting	√	x	• Climbers >2 cm DBH in extraction areas are cut 9-12 months prior to harvesting
5 Growth and yield plots	√	x	• Established for the purpose of assessing logging impacts
6 Road alignment/marking	√	√	• Emphasis is on minimal soil disturbance and efficient drainage
7 Skid trail planning/marking	√	√	• Skid trails are designed to be short; to avoid stream crossings; and are marked with paint or flagging tapes
B Harvest operations			
1 Road construction			
• Main/secondary road	√	√	• Clearings along roadways are prohibited; felling trees to increase radiation on wet stretches is controlled
• Skid trail	√	√	• Maximum width is 4.5 m on gradients up to 20° and 5 m on gradients above 20°; side-cutting allowed on slopes >20°; blading not allowed on slopes <15° and permitted on slopes >15° only during construction; trees >20 cm DBH on a skid trail's alignment should be cross cut and the pieces pushed to the edges
2 Road maintenance	√	√	• Same as in CL practice
3 Felling			
• Tree marking	√	x	• Trees> 60 cm DBH are marked with a paint strip indicating the desired direction of fall
• Felling	√	√	• Trees are felled within 10° left or right of the indicated direction; felling of trees is allowed on slopes >35° only if trees fall along the contour and do not require entry by skidders
4 Extraction (Skidding)	√	√	• Skidding not allowed on slopes >35°; bulldozers must be kept within marked skid trails; reversing bulldozers down skid trails is encouraged; winching of log is also encouraged
5 Bucking and scaling	√	√	• Same as in CL practice: trees are cut into shorter lengths for easier handling and scaled for payments
6 Loading/unloading	√	√	• Same as in CL practice: logs are then loaded or unloaded onto trucks using wheel or tracked-loaders
7 Hauling/Trucking	√	√	• Same as in CL practice: logging trucks with capacity of 40 tonnes are used to transport logs to the mill
8 Rafting and barging	√	√	• Same as in CL practice: logs are rafted and barged (for sinkers) to log ponds or shipside
9 Log pond handling	√	√	• Same as in CL practice: once logs arrived at the log pond, they are graded and marked for shipment
C Post-harvest operations			
1 Drains and culvert	√	x	• Water bars are required on roads and skid trails post-harvest; temporary culverts are removed after harvesting
2 Log landing	√	x	• Roads are used as landings where possible; landings' density is restricted to 0.7 % of the net logging area
3 Damage assessments	√	x	• Assessment of post-harvesting impacts

√ = Applicable x = Not applicable

Table 3.2 A summary of the methods used in assessing the various values

Methods /Values	Timber	Carbon	Rattan	Soil	Water	Wildlife	Time studies
Data collection							
(a) Experimental design	A system of rectangular plots with the principal plot nested with four other smaller plots a) 80 m x 40 m (p+D41rincipal) b) 20 m x 40 m (sub-plot) c) 20 m x 20 m (sub-plot) d) 10 m x 10 m (sub-plot) e) 5 m x 5 m (sub-plot)	Same as for timber enumeration	A system of rectangular plots plots with plot size 40 m x 80 m	100% survey of bared soil area within the selected logging units	Secondary data	Secondary data	Independent observation
(b) Timing of assessment	Before/after logging	Before/after logging	After logging	After logging	Before/after logging	Before/after logging	During logging
(c) Variables measured	Tree/ha Volume/ha Species Crown form, exposure Stem form, class Plot slope	Tree/ha Volume/ha Species Crown form and exposure, stem form, plot slope	Stems/ha Species Plot slope	Skid trails Roads Log landings	Sediment concentration	All vertebrates	Felling and skidding activities
Modelling	Forest growth model using DIPSIM	Carbon flows model using C-REC	None	None	None	None	None
Valuation method	Productive use Market price	Non-consumptive Market price	Productive use Market price	Opportunity costs of timber forgone in bare areas	Non-consumptive use - loss of hydro-electricity	Consumptive use Market price	Opportunity costs

Table 3.3 Schedule of ecological impact assessments relative to logging activity

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Month
Year													Year
1992												A	1992
1993	A								B				1993
1994		B						C					1994
		D								E			
1995					F								1995

Note: A = Pre-logging assessment for timber, carbon and soil biomass in Parcel A
B = Logging of Parcel A
C = Felling and skidding time and motion study in Parcel B
D = Post-logging assessment for timber, carbon and soil biomass in Parcel A
E = Field survey of road, skid trails and log landings
F = Rattan inventory in Parcel A

collected for the rattan value because logging operations had started earlier than this phase of the research.

The field work for the ecological impact assessments involved various people and organisations. The timber enumeration field work was carried out by a team of people under my supervision. The carbon enumeration field work and soil disturbance survey was carried out by a team of people including myself under the direction of Dr Michelle Pinard. I carried out the rattan inventory field work as well as the felling and skidding time and motion studies with a team of people.

3.1.3. Economic assessments

The ultimate aim of the economic assessment of the RIL and CL techniques is to determine whether it would be economical to use RIL to harvest timber. The basis of that decision is an examination of the comparative benefits and costs between the RIL and CL techniques in considering the timber and non-timber values. The weighing of costs and benefits is a common way for decision-makers to decide whether a project should be undertaken or abandoned. In general, a project activity would be undertaken if the benefits outweigh the costs. Conversely, a project would not be undertaken if the costs outweigh the benefits. On the same basis, the decision to adopt RIL techniques instead of CL techniques would have to be weighed against their respective benefits and costs. If the benefits minus the costs of RIL outweigh those of CL techniques, then RIL would be preferred over CL techniques. The method chosen for evaluating the comparative economic costs and benefits of RIL and CL is by an economic cost–benefit analysis (CBA). CBA is a tool commonly used by many. However, there are advantages and disadvantages of CBA. An overview of CBA and its applications is given in section 3.5.

3.1.4. Time frame of economic study

The economic model for the present study covers 60 years with certain non-timber values extracted over a second rotation (year 120) as described in chapter 10. The 60 years is the time frame for managing the natural forest in the Sabah Foundation forest concession (Hepburn, 1979). The 60-year rotation was based on growth capacity of the dipterocarp forests yielding 2.0-4.0 m^3 ha^{-1} per annum (Fox, 1976; Hepburn, 1979), and at the lower limit of 2.0 m^3 ha^{-1} this would produce at least 120 m^3 ha^{-1} in 60 years.

3.1.5. Economic scenarios

There are three theoretical scenarios associated with timber harvesting policy between the first harvest at year 0 and the second harvest at year 60 which would have different economic implications. The first is that the same areas that have been logged at year 0 using RIL and CL techniques will be logged at year 60 using the same techniques (RIL and CL) in the respective areas. This assumes no policy change within the 60 years. The second scenario is that harvesting practices in the future will be aligned to RIL techniques given present global emphasis vis-à-vis the ITTO 2000 objective in bringing tropical forest to sustainable status. This means that areas logged by CL techniques would be logged by RIL techniques at year 60. The third scenario is that present CL harvesting techniques will prevail in all areas in the future. The present study assumes the case of scenario one as it is still uncertain what will happen in the future. The economic implications of scenario two and three are, however, briefly covered in chapter 4 (on timber values).

3.2. Field sampling designs and data analysis

3.2.1. Timber, carbon and soil

The field work for the timber, carbon and soil values was conducted in logging coupe YL3/93 which contained approximately 2,000 ha. The coupe is divided into 43 logging units or compartments of more or less 50 ha each (Figure 2.6). Parcel A is made up of eight out of the 43 logging units and totals 450 ha in a contiguous block (units 29, 30, 32, 33, 34, 35, 35, 36 and 37). The parcel was selected based on its topography being representative of the logging environment in the Sabah Foundation forest concession.

3.2.1.1. Timber

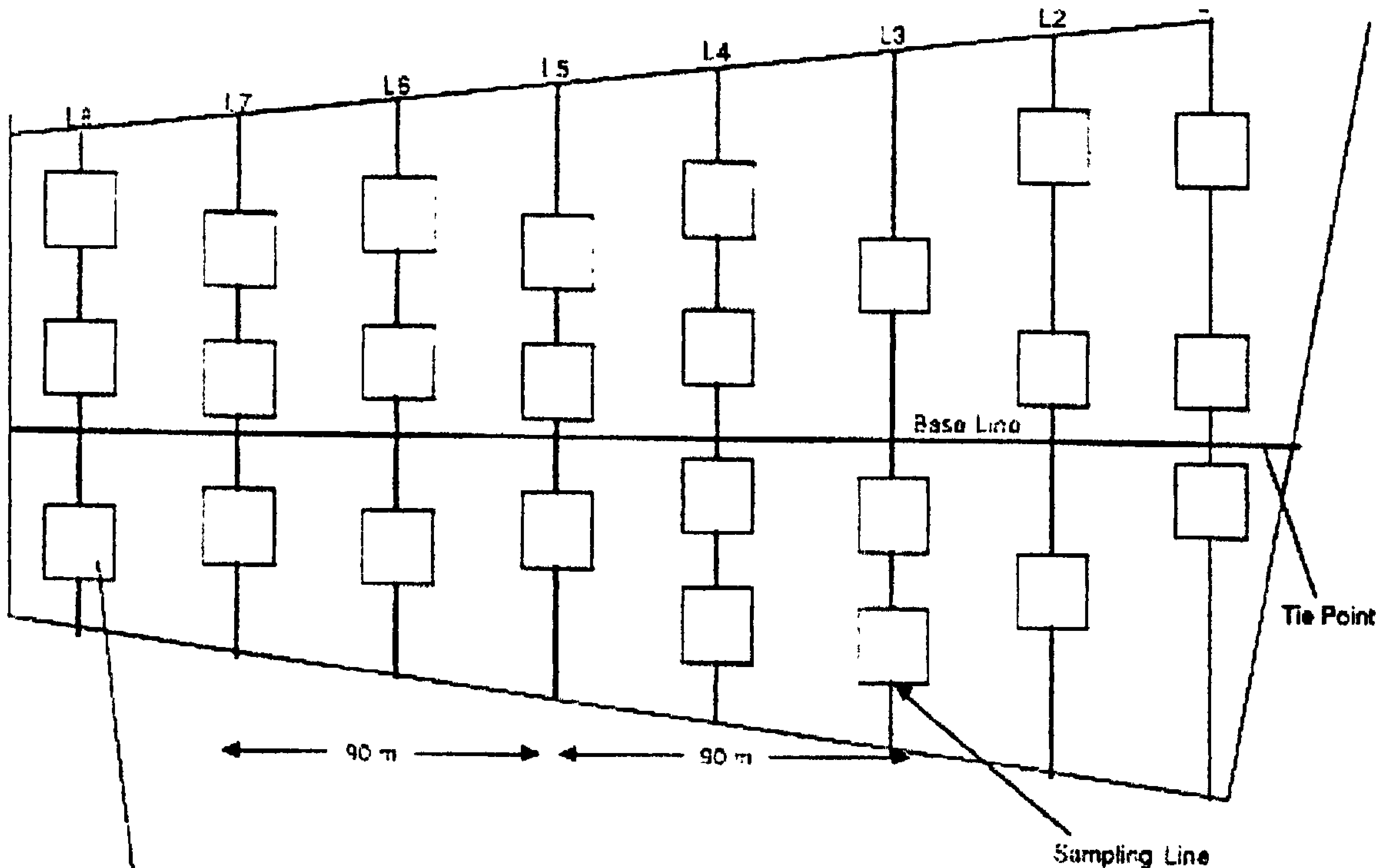
Out of the eight logging units in Parcel A, four units totalling 230 ha (units 30/32/35/36) ranging from undulating to steep topography were randomly selected for assessing the impacts of RIL techniques on vegetation and soil. Another four logging units out of the 35 remaining units in coupe YL3/93 that are near the RIL units were selected to serve as the experimental control units (units 23/38/39/41). The selection of these four CL units was based on similarity to topography in the four RIL units using slope as the main criterion. Units logged by RIL and by CL techniques were also paired according to logging schedule. These measures were to reduce the variability of logging impacts on the residual stand due to differences in slope and soil moisture content.

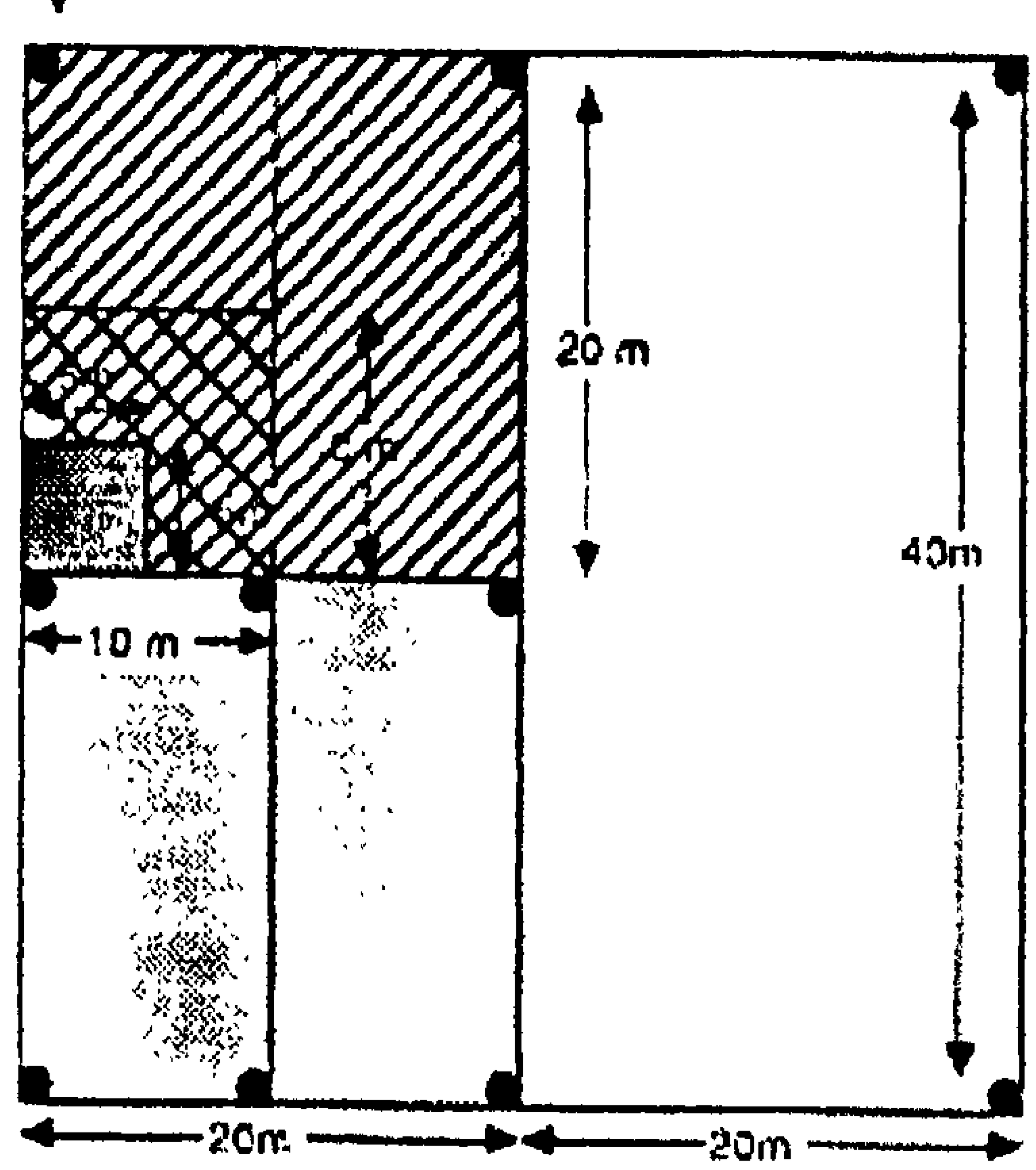
Within a logging unit, sampling lines were located 80 m apart. Approximately 30-35 plots were randomly located along sampling lines separated by at least 50 m to avoid between-plot effects. The average sampling intensity ranges from 20-22 %. Each principal plot contains four nested sub-plots (Figure 3.2). The principal plot is 40 m x 40 m wherein all trees greater than 60 cm DBH are enumerated. In the 20 m x 40 m sub-plots, poles between 20 cm and 60 cm DBH are enumerated. Within this main sub-plot in the 20 m x 20 m sub-plot, saplings between 10 cm and 20 cm DBH are enumerated. In the 10 m x 10 m sub-plot, seedlings of 5 cm to 10 cm DBH are enumerated. Finally, in the 5 m x 5 m sub-plots, seedlings less than 5 cm DBH and greater than 2 m high are enumerated.

In the eight logging units, a total of 265 plots were established. Of these 265 plots, 47 were discarded because they fell on roads, streams, riparian zones, rocky areas, riverbeds and/or were destroyed during road construction after they were set-up. Consequently, only 104 plots in the CL logging units were included in the data analysis and 114 plots in the RIL logging units. For the latter, however, an additional 49 plots were discarded from the logging impact analysis because the forest in these plots was not logged due to the RIL guidelines. A decision had been made *a priori,* that a plot should be excluded from the analysis if there is no logging activity within 30 m of its boundary. The objective of this *a priori* decision was to make the comparison compatible with the objective of measuring the actual impact of logging in the logged areas. This leaves 65 RIL plots used in the analysis. Differences between RIL and CL in the area of each unit that was actually logged are dealt with at a later stage in the analysis.

The variables recorded for all trees in each plot prior to logging were diameter at breast height (DBH), species, crown form, crown exposure, and stem form. Seedlings less than 5 cm DBH in the 5 m x 5 m sub-plots were not measured for diameter but were measured for all the other variables. Other information recorded for each plot was slope, location of skid trails, roads, rocky areas and occurrence of erosion by area. Tree volume was calculated using equations developed by the Sabah Forestry Department (1987). There are 15 volume equations for 15 groups of timber species (Appendix 3.1). The volume equations have been developed as a function of DBH and tree height (measured up to the first branch).

A post-logging assessment was conducted 5-30 days after logging and 8-12 months later for all trees enumerated earlier to assess their fate (present or absent; felled and extracted ; felled but left at stump; uprooted; snapped off; cut off or missing), and damage inflicted to the crown, stem, bark and roots separated into five index classes.





Plot (m)		TREES' DBH (cm)
40 x 40		> 60
20 x 40		20 ≤ 60
20 x 20		10 ≤ 20
10 x 10		5 < 10
5 x 5		<5, >2m tall

Figure 3.3 Experimental designs for collecting vegetative and soil information

3.2.1.2. Carbon

The method and field work for this part of the study was developed and conducted by Dr Michelle Pinard. A full description of the methods was given in her PhD thesis (Pinard, 1995) and a brief description is given below. The carbon stores were assessed before and after logging treatments using the following sampling protocols.

The above-ground biomass was calculated from tree inventory data, and non-tree data (shrubs, herb, palm and herbaceous vine). Above-ground tree biomass was estimated using stem volume-diameter-height relations for different species groups and a biomass expansion factor (BEF) developed for hill dipterocarp forest. The BEF factor converts a tree diameter for a given species to the equivalent whole tree biomass. For the non-tree data, circular plots of 1 m^2 were randomly located within three RIL and three CL units in three topographical positions. All above ground biomass of less than 1 cm diameter at base within the circular plot was cut, weighed, and a sub-sample was oven-dried at 70° C to constant mass. A conversion factor of 50% was used to estimate the carbon content of dry plant tissues.

Below-ground biomass was sampled in the eight logging units using a stratified random design. Coarse roots (>5 mm diameter) were sampled in 50 x 50 cm monoliths of soils extracted to 50 cm depth. Roots were separated from the soil in the field, washed, live and dead roots separated, and sorted; live and dead roots were then weighed, and sampled for dry weight determination. To determine the biomass of coarse roots directly beneath trees (called butt roots) where core sampling was impractical, fourteen partially uprooted trees (20-130 cm DBH) along roadsides and skid trails within the logging coupe were sampled to establish the relationship between butt root mass and DBH. Coarse roots greater than 10 cm DBH within 1 m of the bole of the tree were separated from the soil, cut into pieces of less than 50 kg, washed, weighed and sampled for dry weight determination. Fine roots (<5 cm diameter) was obtained from 5 cm diameter soil cores taken to 10 cm depth, weighed and sampled for dry weight determination. Coarse and fine root biomass are expressed on a per ha basis.

Following logging, tree plots were recensused for damage and survival 5-30 days after logging and again 8-12 months later. The data from the second census at 8-12 months were used in the carbon analysis. The biomass of shrubs and herbs in logged forest was measured one year after logging using a sampling protocol similar to that used for pre-logging measurements. Colonizers and resprouted plants on skid trails, log landings and roads were also measured one year after logging. Coarse root biomass (both living and dead) was measured three months after logging in four logging units (2

RIL, 2 CL) following the protocol described for the pre-logging measurements. The difference between mean coarse root biomass before and three months after logging was considered to have entered the necromass pool. The post-logging assessment did not include fine root mass. It was assumed that fine root mass one year after logging was similar to mass before logging. From the damage assessment data, the following varables were estimated: timber volume extracted; necromass produced from the branches, leaves, stumps and butt roots of harvested trees; necromass produced from trees destroyed during harvesting; and necromass produced from damaged trees that died within the first 8-12 months after logging. Above-ground and butt root biomasses were included in these calculations (Pinard, 1995).

3.2.1.3. Soil disturbance

Soil disturbance in this study refers to the amount of open space occupied by roads, skid trails and log landings. Roads and log landings are devoid of vegetation, and gravelled to subsoil. Skid trail surfaces are variable, and hence, were further classified by degree of disturbance as follows: 1) subsoil exposed, either by blading or heavy bulldozer churning; 2) churned but topsoil mixed with upper layers of subsoil; and 3) compacted by bulldozer with relatively little mixing of topsoil and subsoil.

In the eight logging units, log landings were mapped and measured for their dimension (length and width). For roads and skid trails, their dimension and slopes were recorded. Widths of roads and skid trails were measured every 10-15 m. In addition, sidecast soils (slides) adjacent to roads and skids trails created during road or skid-trail construction were measured. For irregular shaped sidecast soils, the average maximum and minimum distance to the end of the slide were taken.

3.2.2. Non-timber forest products (rattan)

The study was carried out in Parcel A and its adjacent areas within coupe YL2/93 that were logged-over with RIL and CL techniques. There was no pre-logging assessment of rattan abundance in the four logging units because logging activity had proceeded ahead of the inventory schedule.

For the post-logging rattan inventory, two RIL units (units 32 and 35) and two CL units (units 38 and 39) were selected on the basis of similarity in terrain in these units, and their rattan abundance was assessed. The inventory design was the same as that used for the timber enumeration, and the sampling plots overlapped those plots that had been established for the tree enumeration. The exception was that only one plot size was adopted and each plot was 40 m x 20 m (0.08 ha). For each plot, all rattan stems taller than 30 cm were recorded by species, growth form (clustered or solitary), growth stage (mature or immature), length class, and habitat type. The cut-off height of 30 cm was imposed to ensure that only living rattans were recorded, and to reduce inventory cost. The average sampling intensity in RIL and CL units was 16% and 22%, respectively.

3.2.3. Wildlife and hydrology

Secondary data sources were used for these two forest values based on past studies conducted near the research site. The details are given in Chapters 8 and 9.

3.2.4. Felling and skidding time and motion study

The aim of this study was to compare the time consumption, hence the cost efficiency, of felling and skidding operations between RIL and CL techniques.

The study was conducted in logging unit 4 (62 ha) of coupe YT3/94 in Parcel B and unit 3 (50 ha) of coupe YT4/94 that were logged with RIL and CL techniques, respectively (Figure 2.8). These two units were selected because of similarity in the time of the year they were felled (thus climate was comparable). There were two parts to the study. The *felling* study was conducted in October and November 1994, and the *skidding* study between November 1994 and January 1995.

In both logging units, the felling and skidding crews were employees of the same logging contractor and possessed the basic skills to perform their duties. The felling and skidding crews in the RIL sites, however, were trained in RIL techniques while those in the CL sites conducted their work in the manner of 'business as usual'. Felling of trees in both study sites was carried out by one or more two-man teams using a 12 hp chain saw (Stihl 070). Fellers were paid piece-rate based on the volume extracted. The felling contract rate was RM1.30 m^{-3} and included payments for the costs of owning and operating the chain saw. Skidding was carried out using a Komatsu D60 bulldozer in the RIL area and the Caterpillar D7F in the CL area. Although the bulldozers were made by different manufacturers, they were both powered by a 200 hp engine, and have similar features in terms of weight, length, angle blade, etc. The bulldozers belonged to the same logging contractor and the operators and hookmen (assistant to the operator) were paid piece-rate per unit volume extracted.

Two teams of recorders carried out the recording of the time-motion studies. Each team comprised three men and had prior basic training in felling and skidding time-motion recordings. A Swedish researcher conducted the training in Sabah sponsored by the

Swedish University of Agricultural Sciences (Andersson, 1994). The teams were equipped with lap-timing stop-watches, measuring tapes, and essential writing aids etc.

In the field, the teams decided among themselves when and where to carry out observations of felling and skidding operations within the logging units. Once the team had chosen their observation post, they would start the first timing until felling or skidding operations were completed for that day or part of the day. They then moved to another observation post. Only trees or logs above 60 cm DBH were chosen for the time recording. For each tree or log chosen (replicate), the timber species was recorded and the top and lower end diameter of the tree or log as well its length were measured. The operations for each tree or log were timed per felling or skidding operation and not per complete cycle of felling and skidding for a tree because not every tree felled can be immediately skidded to the log landing.

The felling and skidding operations were divided into *productive* and *non-productive* work elements using a similar approach to that described in Marn *et. al.* (1981). The productive work elements for felling were: *searching* for trees to fell; *clearing* the working area around the tree and base of tree, and clearing the escape route; *directing* the fall of the tree (in which fellers discussed and reviewed on-site if they could fell the tree within $\pm$ 10° of the marked direction in relation to the lean of the tree, the standing future crop trees as well as skidding trails); *felling* by removing obstructing buttresses, and making the undercut, backcut or felling cut; and *bucking* the tree to one or more shorter log-lengths (which included the time of walking to the buck position, clearing, preparing and making the cut). The skidding work elements were: *searching* for felled logs to skid; *opening* or constructing skid trails; *clearing* debris at the butt end of the log to attach the winch cable using the bulldozer; *pulling* and *hooking/unhooking* the winch cable from the bulldozer to the fallen log; *winching* the fallen log out of the extraction area with the bulldozer anchored to the ground; *skidding* with the bulldozer moving along with its load; *anchoring* the bulldozer to get traction while winching the log; fighting *hangups* when the log gets stuck in an obstruction; *empty travel* as the bulldozer returns to the stump to take delivery of another log; *blading* or levelling the rut left after the skidding operation on the skid trail to improve traction during the next skidding operation.

The non-productive work elements for felling and skidding comprised *operational*, *mechanical* and *personal* delay. In felling, *operational* delay includes fighting hangups when trees lean on residual trees after cutting; easing a chainsaw jammed in a tree; and stoppage of work due to gusts of wind that affects the direction of tree fall. *Mechanical* delays in felling include filing or replacing saw chains and minor repairs. *Personal* time included rests and lunch breaks. In skidding operations, *operational* delays included bulldozers being stranded in soft ground; splicing and repairing broken winch cables; the bulldozer being called away to ease chainsaws jammed in trees; and fighting hangups when logs fell across the skid trails. *Mechanical* failures include minor repairs. *Personal* time included lunch breaks and rests.

The purpose of dividing felling and skidding operations into work elements was to make the time comparison for each work element comparable between the harvesting techniques. For example, basal area may affect actual felling time but it has no effect on the time required to walk between trees.

The felling operations of 59 trees in each of the treatment areas were timed. For the skidding operations, there were 55 logs recorded in the RIL unit and 58 logs in the CL unit. The results of the felling and skidding times were presented in mean values of felling and skidding times per tree or log, and were calculated by dividing total felling or skidding times by the total number of trees or logs. However, the statistical test was done using each of the individual tree values. A *t*-test at a significance level of 5 % was used to test the null hypotheses that the mean felling or skidding times between treatments were the same. The results of the felling and skidding time-motion study are given in Chapter 4.

3.2.5. Data analysis

3.2.5.1. Response variables of forest disturbance

The response variables of logging disturbance on the timber and non-timber values are listed in Table 3.4. For example, the logging impacts on timber values are quantified in terms of the number of trees extracted, destroyed, and damaged as response variables. The key criteria in choosing these response variables were that they were relatively easy to measure in the field.

3.2.5.2. Approach to data analysis

When the measurements of the variable before and after impact are directly comparable then the actual impact of logging (value pre-logging minus the value post-logging) is calculated separately for each sample unit. Additionally, the mean (and standard error) for each treatment (RIL or CL) was calculated and then tested for between treatment differences (see section 3.2.5.3 below).

Table 3.4 Response variables used to indicate impacts of RIL and CL techniques

Forest values	Response variables	Units
1 Timber	1.1 Stand density 1.2 No. of trees extracted 1.3 No. of trees destroyed 1.4 No. of trees damaged	Tree per ha Tree per ha Tree per ha Tree per ha
2 Carbon	2.1 Similar to 1 above	Tonnes per ha
3 Soil	3.1 Road area 3.2 Skid area 3.3 Log landing area 3.4 Road length 3.5 Skid length	Hectare (ha) Ha Ha Km Km
4 Rattan	4.1 Stand density	Stems per ha
5 Hydrology	5.1 Soil loss 5.2 Sediment yield	Tons per ha Tons per ha
6 Wildlife	6.1 Number of individuals of selected mammal species	Individuals per ha
7 Time motion study	7.1 Time	Minutes

If the direct measurements of the variable (as in the case of non-timber forest products, water and wildlife values) were not made before impact but only after impact, their values were estimated for before impact using covariates (e.g. for soil erosion, if the plots had different mean slope angles) in the main analysis (see section 3.2.5.3 below). If there was no basis for doing this, then the plots were treated as equal before logging, and the main comparison between the impacts of the RIL and CL treatments was carried out by simple comparison of the level of the variable between the plots post-logging.

3.2.5.3. Statistical analysis

The statistical analysis starts with a check on the normality of the data (by plotting of histogram of frequency distribution) and, if necessary, the use of appropriate procedures to increase normality such as data transformation. Once the normality criterion was met, the appropriate statistics (parametric or non-parametric) were used to test the differences between the treatments. The programmes used were Microsoft Excel and MINITAB (Version 10.2).

The hypothesis testing for most of this study is examining if there is a significant difference in the respective response variables between logging treatments. For a parametric test that involves such two-sample hypotheses, the single factor analysis of variance (ANOVA) or the two-sample Student *t*-test may be used. Both procedures give identical conclusions (Zar, 1984). For this study, the Student *t*-test is adopted unless otherwise stated. The Student *t*-test is robust enough to stand considerable departures from its underlying assumptions, that both samples come at random from normal populations and with equal variances, especially when a two-tailed test is considered. The calculation of the *t*-value for testing the hypothesis concerning the difference between two means is described in Zar (1984 pp 126-130). The non-parametric test analogue to the two-sample *t*-test is the Mann-Whitney test. For this test, the actual measurements are not employed, but instead the ranks of the measurements are used (Zar, 1984 pp 138-144).

Simple linear regression was also used in this study to explain and predict the relationship between two variables. For example, the abundance of rattan (section 3.2.2) was compared with slope angle to test the assumptions made on the abundance of rattan prior to logging. The techniques for testing equality of two population regression coefficients (comparing two slopes) involves the use of Student's *t* in a fashion analogous to that of testing for differences between two population means. The test statistic is described in Zar (1984 pp 292-295). If the comparison involves more than two slopes, this calls for the utilization of a procedure known as analysis of covariance (Zar, 1984 page 300-301).

A 5 % significance level was used in the statistical inference. This significance level is usually considered to give a "small enough" chance of committing a Type I error (the null hypothesis is rejected when it is in fact true), while not being so small as to result in "too large a chance" of committing a Type II error, i.e. not rejecting the null hypothesis when it is false (Zar, 1984). T-tests are two-tailed using pooled variances unless otherwise stated. In making so many separate t-tests on the data with a 5 % significance, it is inevitable that a Type I error (1 in 20 cases) will be committed.

3.2.5.4. Reporting variability about the mean

In this study, the measure of variability about the mean is expressed by the use of the standard error (SE) unless otherwise stated. The intention is to provide the reader with a statement about the precision of estimation of the population mean.

3.3. Forest growth modelling

Given the long period required for trees to reach commercial maturity (in the order of 10 to 80 years), forest growth models are useful tools to simplify the understanding of the biological dynamics of forest, and in investigating forest management alternatives. As such, models can be broadly aggregated into two categories i.e. models for understanding and models for prediction (Vanclay, 1994). Models for understanding are intended to "explain how the system works and lead to an understanding of why it behaves in a particular manner to create a better understanding of the system modelled" (Adlard *et.al.,* 1988). Conversely, models for prediction are used to provide yield predictions for planning and management. Models for prediction are relevant to this study. A model may be *deterministic* or *stochastic*. A deterministic growth model always gives the same result given the same initial conditions. Such models, however, do not represent the real situation because real forest stands may vary according to the environment. Conversely, a stochastic model attempts to predict growth given certain conditions, and the results will vary even if the same conditions were used in subsequent simulation.

3.3.1. Basic concepts of forest growth modelling

Vanclay (1994) classified growth models into five classes i.e. whole stand models, size class models, single-tree models, succession models and process-based models. Whole stand models are those in which the basic variables of modelling are stand parameters such as stocking and stand basal area to predict the growth or yield of the forest (e.g. Clutter, 1963). Size-class models originate from the classical method of stand table projection that provides information regarding the structure of the stand. Forest structure may be formed into cohorts or group of trees with similar characteristics on the basis of species, diameter, height or crown illumination (e.g. Wan Razali, 1988). Single tree models use individual trees as the basic unit of modelling (e.g. Ong and Kleine, 1995). Succession models attempt to model species succession (e.g. Botkin, 1993). Finally, eco-physiological models (also called process-oriented or mechanistic models) attempt to mimic the growth of vegetation in "gaps", created by windthrow, lightning, insect calamities etc. (e.g. JABOWA models (Botkin *et.al.,* 1972); and FORET models (Shugart, 1984)). These models are built on system concepts and physiological processes of natural forest (light, temperature, and soil nutrient level) to model the photosynthesis and respiration. The major difference setting these models apart from others is the fact that they do not use any time-dependent formulations of growth (as in growth function models), but instead forest dynamics are generated entirely endogenously by modelling real eco-physiological processes by their rates of change in terms of differential equations (Appanah *et.al.,* 1990).

While models may differ in their purpose and approach in simulating growth, they have commonality in three areas. The first is that models must have input parameters (or state variables) that best indicate growth. A good growth indicator must exhibit the interacting forces of above- and below-ground competition; while being easy to measure, and reduce bias in the field. Tree height, diameter, and crown size are some of the best indicators to predict growth (e.g. Vanclay, 1989; Silva *et. al.,*1994). All of them need to be incorporated separately if their effect on growth is, to some extent, independent.

Secondly, it is common to expect some aggregation of tree species into several groups. This is inevitable for tropical forests because of the large number of tree species with diverse growth habits. It is, therefore, impractical to develop growth functions for each individual tree species, but necessary to reduce them to a more manageable number. Besides, individual tree-growth prediction may have little practical potential in stands containing a diversity of species and age class (Shugart, 1984). The classification of plant species into groups is a large subject with a surplus of alternative terminology, philosophies, and methodologies (Healey, *pers. comm.*). The complexity of this subject can be seen by the various closely linked concepts such as "guilds", "functional groups", "tolerance classes", and "traits".

Thirdly, forest growth models contain three main components, namely increment, mortality and recruitment. This follows the basic tenet that a tree must either remain in its size class, grow into another class, get harvested or die. Growth models may be developed using empirical equations (mathematical expressions based on observed value), a transition probability matrix, or be process-based to facilitate growth projection. Empirical growth equations are developed from data that do not identify the individual tree, and may be presented as mathematical function of growth versus diameter, site quality or height. Transition matrices are a logical extension of empirical growth equations, and use ratios to project growth (e.g. Usher, 1966; Buongiorno and Michie, 1980). Transition matrix models are useful when ample data are available, but have not been analysed or incorporated into regression equations. They are an efficient means of summarising data, but rarely leads to an understanding of the process involved. These models use a probability matrix life-table to predict growth (e.g. Usher, 1966; Alder, 1970). Process-based growth models attempt to model the growth using environmental variables (e.g. light) which influence plant physiology by representing the effects on growth of their rates of change by using differential equations.

Growth functions have been extensively studied by different workers. For example, Swaine and Hall (1987) found growth rate of individual trees to be significantly correlated with previous growth rate, and with diameter. They also found that mortality did not differ between diameter size class, but was negatively correlated with previous growth rate and crown illumination. Silva *et.al.* (1994) instead found poor correlation of diameter and growth rate, but when the mean growth rates of size classes were compared, they found a strong correlation between diameter and growth rate. They also concluded that crown illumination was the main determining factor of growth. However, it is often very difficult to see the crowns of tall trees in rainforest (Vanclay, 1989).

There are models that simulate competition based on neighbourhood analysis. These studies evaluate performance of trees versus proximity to and species of nearest neighbours. For example, Kohyama (1987) modelled competition due to the density and basal area of trees in the same plot as each individual to predict the growth rates of each individual. Primarck *et.al.,* (1985) studied the significance of distance and size. In a separate study, Ashton and Hall (1992) estimated survival of saplings and seedlings by assessing size (height), age and vigour (number of leaves per unit stem).

Vanclay (1992) reviewed various approaches to simulating regeneration as a whole (the development of trees from seeds or seedlings) and specific recruitment (i.e. the number of stems growing into some specified nominal size class). Alder (1979) developed a regeneration model based on height classes, while Vanclay (1988) simulated regeneration starting with seedlings that survived their first year after germination. Others predicted regeneration of trees using environmental variables (habitat, slope, aspect, elevation), distance to seed source, residual basal area, and time since disturbance (Ferguson *et.al.,* 1986). Some models employ regeneration sub-models to predict the growth of regeneration from seed until it is recruited into the main model (e.g. Hamilton and Brickell, 1983; Stage and Ferguson, 1982). The rationale is that the number of seedlings in a given year is a probabilistic function of the simulated environment at the forest floor, species regeneration characteristics and random factors. The establishment of trees is a stochastic process.

For recruitment modelling, Usher's (1966) matrix model for Scots pine predicted recruitment as a static proportion of the number of trees in the larger size classes, and thus recruitment increased as stand density increased. More realistic matrix approaches may predict recruitment diminishing with increasing stand density (e.g. Buongiomno and Michie, 1980). Other approaches attempt to predict the number of stems recruited as a function of stand condition. Hann (1990) predicted recruitment with an exponential function of site index, stand basal area, and basal area in the smallest size class. Vanclay (1992) used a two-stage model to predict recruitment. The first stage predicted the probability of the occurrence of any recruitment from stand basal area and the presence of that species in the existing stand. These probabilities can be used stochastically or deterministically by summing the probabilities of initiating recruitment. The second stage indicated the expected amount of recruitment, given that it is known to occur, and employed stand basal area, the relative number of trees of that species in the stand, and site quality. One of the difficulties in modelling recruitment is the variability in regeneration due to stand condition, climate and periodicity of mast years.

3.3.2. Growth models required for this study

The basic requirements of the growth model for this study are summarised in Table 3.5. The input parameters could be one or a combination of the following variables: diameter, species, and/or crown form. It must be able to handle timber quality for valuing the final crop. The outputs of the model are stand density and stock of harvestable trees (over 60 cm DBH) by species or species grouping.

3.3.3. A review of growth models used in Sabah

3.3.3.1. The *DIPSIM* growth model

DIPSIM was developed by the Sabah Forestry Department to simulate stand growth of dipterocarp forests in Sabah, Malaysia for up to 60 years (Ong and Kleine, 1995). It is a single-tree list spatial model which uses information about the position and size of neighbouring trees to simulate the growth of individual trees in a stand (Vanclay, 1994). It also accounts for species differentiation, tree size, site productivity, and competition in the model. *DIPSIM* uses diameter as the growth indicator and employs individual tree and stand attributes in regression equations. The main features of the model are summarised in Table 3.6.

Table 3.5 Features of conceptual forest growth model suitable for the present study

INPUTS	- Must be compatible with the inventory design where each plot consists of a principal plot of 40 m x 40 m with four nested sub-plots 40 m x 20 m; 20 m x 20 m; 10 m x 10 m and 5 m x 5 m for trees >60 cm DBH, 40-60 cm, 20-40 cm, 10-20 cm and $\leq$10 cm, respectively. - Individual tree entry by DBH, species, and condition before logging (crown form and stem) and after logging (damage to crown, stem, bark, alive/dead).
PROCESSES	- Either a size class model driven by ingrowth, mortality and outgrowth or an eco-physiological (process) model but the former is preferred because only basic and routine data were collected. - An economic model that handles timber quality for timber pricing. - Simulation of up to 60 or 120 years.
OUTPUTS	- Final output in a stand table by DBH classes; species grouping (dipterocarp, non-dipterocarp, pioneer, others); timber quality; tree volume (m^3) ha^{-1}.

Table 3.6 Features of *DIPSIM* forest growth model

INPUTS	- Individual tree (>10 cm DBH) by species and DBH collected in plots (L-shaped) or permanent plots (1 ha sub-divided into 20 m x 20 m). - Site quality based on land form and parent material in two categories (good or poor) assessed from soil survey and permanent sample plot data. - Stocking of potential crop trees (20-39 cm) and trees >40 cm DBH; slope; felling intensity; damage level; and harvesting method (tractor logging; reduced impact logging or skyline).
PROCESSES	- *Growth* (basal area increment) of individual tree is a function of *species* (20 species groups in 20 growth equations, 11 for dipterocarps and 9 for non-dipterocarps/pioneers), *site quality, total stand basal area* and *overtopping basal area* (the total basal area in the 20 m x 20 m plot of trees with DBH greater than that of the tree to be simulated). - *Mortality* is classified into 7 timber groups (non-pioneer or dipterocarps (3), pioneer (1), macaranga (1), others (1). Mortality in the non-pioneer group is expressed as annual percentage of dead trees ha^{-1} per DBH class based on data obtained from permanent sample plots. The user can change the mortality rates in the model as required. The pioneer group is estimated by the logistic function as a function of DBH, tree basal area and stand basal area. The mortality rate for non-dipterocarps is 5 trees ha^{-1} yr^{-1}; for light hardwoods 2 trees ha^{-1} yr^{-1}; and for dipterocarps 0.1 trees ha^{-1} yr^{-1}. - *Recruitment* rates are classified into 7 timber groups similar to those in the mortality model. - *Harvesting* is allowed only if a stand meets the slope criteria, the minium stocking standards for potential crop trees (20-39 cm DBH) and if there are more than 5 trees ha^{-1} >40 cm DBH. - *Logging damage* simulation requires the specification of the proportion of trees expected to be killed in two DBH classes (10-39cm; > 40 cm DBH). The harvesting model then randomly selects trees and removes them from the simulation database.
OUTPUT	- Volume (m^3) ha^{-1} and trees ha^{-1} by DBH classes and species grouping; volume increment tables; harvesting tables.

Source: Ong and Kleiner, 1995

The growth functions in *DIPSIM* have basal area increment of individual trees as the dependent variable. The independent variables consist of basal area of individual trees, site quality, stand basal area and overtopping basal area. The stand basal area and overtopping basal area account for competition. Basal area refers to the total surrounding stand basal area of all trees greater than 10 cm DBH within the 20 m x 20 m plot in which data is collected. The overtopping basal area is the basal area of all surrounding trees whose diameter is greater than the individual tree to be modelled. There are 20 growth functions in *DIPSIM* which represent 20 growth groups. The 20 groups (11 for dipterocarps and 9 for non-dipterocarps/others) also represent the most common and commercially important trees of the dipterocarp forests.

To estimate tree mortality, *DIPSIM* divides timber species according to their demand for light or growth response into two groups. The pioneer group consists of light-demanding species which includes the dipterocarp and non-dipterocarp species divided into seven groups. The non-pioneer group consists of all species not included in the pioneer group. *DIPSIM* uses two approaches to model mortality: (1) the adoption of logistic functions to predict the probability of mortality from tree size and stand competition for the pioneer species; (2) a size-class approach was adopted for the non-pioneer (slow-growing) species based on an annual percentage of mortality per diameter class. The second approach was adopted because an attempt to model mortality for non-pioneer species using a logistic function gave unsatisfactory results.

The *DIPSIM* recruitment model predicts recruitment rates for species in seven timber groups similar to those used in the mortality model. Recruitment was based on average annual rates (trees ha^{-1} yr^{-1}) for each of the seven groups according to five stand density classes expressed as basal area (m^3) per hectare (<10, 10-20, 20-30, 30-40, >40). The recruitment rates were developed from long-term growth and yield data.

In simulating harvesting, *DIPSIM* allows the user to specify the simulation period, the annual harvest level, the slope restriction, the minimum economic cut, the amount of harvesting damage and the utilisation standard. Harvesting simulation will proceed only when there is sufficient stocking. *DIPSIM* provides an internal checking of the minimum stocking standard for two diameter classes, namely 20-39 cm DBH and greater than 40 cm DBH. Harvesting operations inevitably cause damage to residual trees. In *DIPSIM*, the user specifies the percentage of trees expected to be destroyed in two size classes (10-39 cm and > 40 cm). The harvesting module then selects trees randomly, and removes them from the simulation process.

DIPSIM accepts data collected from either permanent sample plots of 1 ha sub-divided into 20 m x 20 m plots or management inventory plots measuring 72.5 m x

20 m in an L-shape. *DIPSIM* predicts the future stand based on the growth processes of diameter increment, mortality and growth of individual trees. The model's output is in terms of trees per hectare, basal area per hectare and volume per hectare by species groups (dipterocarp and non-dipterocarp) and by diameter class of trees greater than 10 cm, at 10-year intervals. However, the model does not give the economic output as desired for the conceptual growth model for this project.

DIPSIM is suitable for application in this study. In the first instance, the growth information to run *DIPSIM* is derived from 20 m x 20 m plots similar to those which the RIL project uses for data recording, although they differ in the diameter of trees enumerated. In the case of *DIPSIM*, all trees greater than 10 cm DBH were enumerated in the 0.04 ha plot whereas only trees 10-20 cm DBH were enumerated in the 0.04 ha plot for the RIL project. This disparity can easily be reconciled because the missing diameter classes required in *DIPSIM* are available from the other nested plots. A further advantage of *DIPSIM* is that the growth processes have been formulated with due consideration to the forest dynamics of the logged forests of Sabah, Malaysia. *DIPSIM* has been validated with an up to 20-year old data set collected from permanent sample plots throughout Sabah (Ong and Kleiner, 1995). However, *DIPSIM* does not provide output by timber quality which is an important determinant of timber price.

DIPSIM is written in a 'C' language (CLIPPER 5.2) and runs on a PC-80386 machine. It requires approximately 2 Kbytes of RAM and 50 megabytes of hard disk. The model is accessible with permission of the Sabah Forestry Department.

3.3.3.2. *FORMIX* growth model

FORMIX is a process-oriented stand table developed by Bossel and Krieger (1990) for the Malaysian lowland dipterocarp forest. The basic unit of the *FORMIX* model is similar to the gap-models of Botkin (1972) and Shugart (1984), and is based on the physical principles of energy and mass conservation. *FORMIX* differs from other models in that it does not use any time-dependent formulations of growth (as in growth table models). The main features of *FORMIX* are summarised in Table 3.7.

The basic *FORMIX* model subdivides the forest structure into five canopy layers, namely seedlings, saplings, poles, main canopy and emergents (Schafer *et. al.*, 1992). The heights of each layer are model parameters and can be measured in the real system. Changing the height structure could lead to an adaptation of the model to different site conditions.

Table 3.7 Features of the *FORMIX* forest growth model

INPUTS	- Number of trees and biomass (state variables) in each of five canopy layers corresponding to five development stages: seedling, sapling, pole, main canopy trees and emergent trees - State variables collected in 20 m x 20 m plots. - Parametrization of tree physiological and soil-biological variables.
PROCESSES	- *Light attenuation*: each canopy layer has a unique relative position with respect to the other layers and this position determines the amount of light received for photosynthetic production. Light attenuation within the forest canopy is approximated by the Monsi-Saeki formulation of the Lamber-Beer law of exponential light attenuation. This determines the incident radiation for each leaf layer as a function of the radiation above the canopy. - *Photosynthetic production* is based on an exponential light distribution within the crown as a function of the cumulative leaf area index of this layer (sum of all leaf layers in each canopy) and the photosynthetically active radiation above the canopy. The light response curve of leaves is approximated by a Michaelis-Menton formulation. It provides the gross photoproduction rate as a function of the incident radiation. - *Height growth* in biomass is a result of photoproduction, respiration and biomass losses through biomass turnover and deadwood losses. - *Transition* of tree numbers from one layer to another is activated when the average height of trees within a layer reaches a certain threshold height. - *Tree mortality* is accounted for in each layer by the product of the number of living trees and the specific mortality rate, and is dependent on the canopy density (crowding) in that layer. In addition, the mortality of main canopy and emergent trees is determined by a random process, and it is assumed that there is a 50 % chance of the dead trees to falling. The falling trees undergo a random process to determine the fall direction because the model has a spatial or gap component. - *Seed production* is simulated by a random process at the beginning of each year. A good seed year results in a survival of 500 seeds per mature tree, and a bad seed year only 20 seeds per mature tree. Seed production is determined by the availability of mature trees in the main canopy and in the emergent layer. The number of seeds produced is a function of time (at time intervals of five years); a damage factor is considered. 70 % of the seeds remain in the plot of their origin, 30% move to the determined target plot. - *Logging* operations will decrease the number of stems and the wood biomass, not only for the emergent layer, but via logging damage to the various layers.
OUTPUTS	- Stem-diameter distribution; basal area; stand profile (height); stand density; mortality rates; biomass per hectare by species group

Source: Bossel and Krieger, 1990; Appanah *et. al.* ,1991; Bossel and Krieger, 1994.

Additionally, the model caters for species differentiation according to their maximum height. The different species present in tropical lowland dipterocarp forests were grouped into five different "physiognomic groups" namely shrubs/herbs, small trees, understorey, main canopy and emergents. The main difference between the physiognomic groups is their response to the incoming solar radiation (at different heights) calculated using mathematical equations. The emergent trees, representing the dipterocarps, are shade-tolerant (Appanah *et. al.,* 1996), i.e. their photo-productive capacity at lower radiation levels is high compared with light-preferring species or shade-intolerant species.

FORMIX's dynamics are generated by the eco-physiological processes of energy assimilation, dissimilation and storage. The change in energy at each of the five canopy levels is computed from photosynthesis (total photo-production) minus respiration and mortality. Photosynthesis is modelled using mathematical equations dependent on the light intercepted, adjusted for attenuation at each canopy layer. If there is energy surplus in a layer, trees will grow in height until they reach into the next higher layer.

For each of the five canopy layers, there are two differential equations describing the rate of change of tree number and tree biomass (known as state variables). The rate of change of tree number and biomass are calculated by integrating the transition rates representing trees growing into one class from a lower layer and leaving the class to the next canopy layer, and accounting for density-dependent tree mortality just within classes. The transitions will be activated if the diameter of trees within a particular class exceeds a given threshold value. A random number determines the death of a big tree (larger than 25 m) and falling direction. Only trees of the main and emergent layers are assumed to produce seeds. Seed production is determined by the number of individuals in the two canopy layers and survival rates.

Scenarios for seeding, thinning, cutting, and logging damage are introduced by changing the relevant state variables. The same flexibility is provided for temperature, water and nutrients.

Users need only to provide two input variables for a simulation run, i.e. stem number per hectare and biomass per hectare for each of the five canopy strata. The input values for the physiological variables are collected from permanent sample plots of 100 m x 100 m and the user input variables are from temporary sample plots measuring 20 m x 20 m.

A validation run of *FORMIX* on primary (Pasoh Forest Reserve, Peninsula Malaysia) and logged forests (Deramakot Forest Reserve, Sabah) in Malaysia over 400 years showed satisfactory results in respect of natural forest development, timber yield and wood biomass when compared to empirical data (Appanah *et. al.,* 1991). Nevertheless, Schafer *et. al.,* (1992) acknowledged that the model's physical parameters in the following areas need further refinement:

- light response curves for different physiognomic tree groups;
- light attenuation rates for different canopy species or groups;
- crown diameter and tree geometry data for different species groups;
- carrying capacity of different sites in terms of basal area;
- structure of different natural forests;
- mortality and transition patterns of different canopy layers and species groups;
- partitioning of biomass as a function of development stage;
- specific respiration rates of tree compartments as a function of temperature

The outputs of *FORMIX* are stand density (stems ha^{-1}), basal area (m^2 ha^{-1}), volume (m^3 ha^{-1}), biomass (tonnes ha^{-1}), stem-diameter distribution and stand profile. It does not provide stand and stock tables by species utility groups or information on timber quality. This information is a prerequisite for valuing timber at the end of the simulation run.

In order to use *FORMIX* for simulating growth as specified in this study, it would be necessary to obtain new physiological parameters for the forests in the study area because existing parameters in the model are for the Deramakot and Pasoh forests. The acquisition of this information would be costly and time consuming.

FORMIX is written in TURBO PASCAL and requires a PC-80386 processor running under DOS 2.0 or a higher version. A graphic adapter is required to display species groups. The program occupies about 150 KBytes of disk space and requires at least 640 KBytes of RAM. *FORMIX* can be used with permission from the Forest Research Institute of Malaysia or the Sabah Forestry Department.

3.3.3.3. Carbon Recovery Model (C-REC)

C-REC simulates changes in forest carbon pools following selective logging in a dipterocarp forest (Pinard, 1995). The model concept is similar to that of Bossel and Krieger (1994) but includes necromass and incorporates more complexity to account for stem and crown damage.

C-REC subdivides the stand structure into four layers corresponding to four "physiognomic size groups" according to tree diameter (trees 1-10 cm DBH for (seedlings and) saplings, 10-25 cm DBH for poles, 25-45 cm DBH for mature trees and greater than 45 cm DBH for emergents).

For each layer, trees are assigned a diameter, wood density, stem damage class, crown projection area, and commercial status (Table 3.8). Each tree is converted to the equivalent whole tree biomass using a biomass expansion factor (BEF) according to Kira's (1978) and Brown *et. al.*'s (1989) findings for tropical forests. For dipterocarps, two BEF equations are used: one for trees below 10 cm DBH and the other for trees greater than 10 cm DBH. Only one BEF equation is adopted for pioneer species. The annual biomass remaining in each size class is calculated from its gross photosynthesis capacity (standing stock plus newly recruited seedlings) minus the sum totals of respiration, litter fall, logging debris and mortality after subtracting the volume extracted. The formulae and basis of calculating the gross photosynthetic capacity for each size class are similar to those developed by Bossel and Krieger (1994) for *FORMIX*. The amount of tree debris is calculated from trees felled using appropriate regression equations, and the debris is accumulated in a necromass pool. The necromass pool allows for losses due to natural decay and transfer to soil carbon. The logging module in C-REC separates logging damage of non-fatally and fatally damaged trees (e.g. uprooted, missing, snapped-off). Fatally-damaged trees are removed from the database while a growth reduction factor is imposed on non-fatally damaged trees.

Required data inputs are pre-logging stand structure, species composition, decomposition rates, soil carbon pool, ratio of root biomass to above ground biomass, growth rates for undamaged and damaged trees and stand mortality rates. The tree data are collected from the same plots as designed for this study. The outputs are carbon stored over time, by pools; stand structure and commercial timber volumes over time. The additional outputs that would have to be built in this model to be used for the timber yield projections in this thesis project are change in species over time, timber value by quality and species groupings, and stocking by DBH classes.

C-REC is accessible for the purpose of this study from the developer (Dr. Michelle Pinard). It is written in Q-BASIC language and runs on a PC-80386. It requires two megabytes of RAM and 50 megabytes of disk space.

Table 3.8 Features of the Carbon Recovery (*C-REC*) forest growth model

INPUTS	- Individual tree by DBH, species, stem damage class/index, wood specific gravity. - decomposition rates for wood and leaf litter. - soil carbon pool (CO_2 evolution). - root biomass ratio to above ground biomass. - growth rates of damaged and undamaged trees by DBH class. - stand mortality rates by DBH class and damage class. - volume of timber removed (m^3 per ha) at t_0. - area covered by skid trails (%) at t_0. - proportion (%) of remaining trees fatally damaged (dead trees), otherwise damaged. - data collected from principal plot (80 m x 40 m) and sub-plots (40 m x 40 m; 20 m x 20 m; 10 m x 10 m; and 5 m x 5 m) corresponding to >60 cm DBH; 40 cm to 60 cm; 20 cm to 40 cm; 10 cm to 20 cm DBH; and < 10 cm DBH converted to per hectare for input.
PROCESSES	- *Merchantable wood volume* is converted to whole tree biomass using the expansion factor in Kira (1978) (for non-pioneer species, a distinction is made between >10 cm DBH and <10 cm DBH using separate equations; there is no separation in pioneer species). - Annual *growth* increment/mortality/recruitment by non-pioneers and pioneers. - *Damage* inflicted on trees is randomly assigned by four damage indices (0,1,2,3); mortality probability has three classes of entry (0.6, 2.0-0.4, 1.0-0.3) for different size classes; growth (correlated with respiration rate) drops for each class with damage based on damage indices - *Recruitment* onto disturbed areas (skid trails, log landings) is differentiated by species (pioneer trees for first 25 years after which other species). - *Coarse woody debris* from timber residuals is calculated using Kira's (1978) average; small and fine woody litter is derived from Burgouts *et. al.* 's (1992) estimate. - *Seedling recruitment* is estimated using Bossel and Krieger's (1990) numbers.
OUTPUT	- Carbon stored in wood, soil, and necromas over time. - Tree volume (m^3) ha^{-1} and density (tree ha^{-1}) broken down into pioneers, and non-pioneers by diameter classes

Source: Pinard, 1995

3.3.4. Choice of models for this study

Among the three growth models reviewed, *DIPSIM* and C-REC are chosen for this study (for timber yield and carbon storage projections, respectively) but with further modifications described in the following section.

In terms of data input for *DIPSIM*, the individual tree variables (DBH, species, form) collected from 20 m x 20 m inventory plots are compatible with those collected for the RIL project. Although in the latter project only trees 10 to 20 cm DBH were enumerated in the 20 m x 20 m plots, the missing information on trees greater than 20 cm DBH is captured in the other nested plots and could be used for the model. *DIPSIM*'s growth processes are constructed from regression equations as a function of diameter increment, ingrowth and mortality. These are much simpler and more easily initialised than in *FORMIX* which is based on physiological parameters. The growth parameters for *DIPSIM* have been validated by the Sabah Forest Department using permanent sample plot data up to 20-years old (Ong and Kleiner, 1995). In terms of output, *DIPSIM* generates stand and stock tables (by species group and DBH) at five-year intervals. It, however, does not generate the timber quality information required for the economic analysis, but this variable is generally lacking in most growth models, presumably due to the lack of growth and yield information to predict reliably the future timber quality. For this study, timber quality is assigned to each merchantable log at the end of the simulation period. This assignment of quality is done on the basis of Sabah's log grading rules and by determining the proportion of each log grade in a hectare of forest. Because of lack of available data, this assignment gave the same proportion of trees in each grade between RIL and CL. It was decided that tree damage data recorded immediately after logging could not be used to determine the log quality of the trees harvested 60 years later.

The definitions for Sabah's log grades have been given in the preceding chapter (Chapter 2: Appendix 2.2). Briefly, there are seven timber grades in use. These are the FAQ, SSQ, SQ, MQ, SM, SSM and MQL in descending order of quality. The grade of a timber is determined by its species, defects (both natural and mechanical), physical form and length. These determinants in turn determine the timber price. The proportion of grades for a hectare of forest was determined from actual log grade data from within the logging area in which the RIL project is sited (YL2/93) as well as from adjacent logging coupes; the details are given in chapter 4: section 4.2.2.3.1. The approach used in this valuation can be illustrated by an example; assuming that the simulated yield is 100 m^3 ha^{-1}, and the timber grade of SQ and above is 70 % which is equivalent to 70 m^3 ha^{-1}, the value of the SQ and above is calculated by multiplying the proportion of SQ and above grade by the market price for that timber species or species group.

C-REC was developed for modelling biomass pools for the RIL Project (Pinard, 1995). As such it is directly applicable to this study after minor changes to suit the purpose of this study (Pinard, *pers. comm.*).

3.4. Cost–benefit analysis

3.4.1. Definition of cost–benefit analysis

Cost–benefit analysis (CBA) is defined by Price (1989) as an economic appraisal of the costs and benefits of alternative courses of action, whether those costs and benefits are marketed or not, to whomsoever they accrue, both in present and future time, costs and benefits being measured as far as possible in a common unit of value called the numeraire.

The main aim of economic CBA is to value changes in consumption, particularly how much additional consumption arises when one more factor of production and good becomes available (Price, 1989). In this respect, economic CBA differs fundamentally from financial CBA; the latter is concerned mainly with profit-maximization. Forestry projects, for example, exist to increase consumption either for shareholders, project workers, or citizens generally. The measure of consumption in monetary terms is indicated by the willingness of consumers to pay for goods and services to derive satisfaction from consuming them (Pearce and Turner, 1990). The willingness to pay (WTP) concept thus gives an automatic monetary indicator of preference or the strength of individuals' preferences. However, WTP as measured by market prices may not accurately measure the whole benefit to either individuals or society. The reason for this is that there may be individuals who are willing to pay more than the market price for the same benefit. The 'excess' benefit that they obtain is known as consumer surplus. Consumer surplus is not an absolute figure, but an excess value over that of WTP and what was actually paid (Price, 1989). In this case, the total value of consumption (benefit) is the sum of market price plus consumer surplus. The WTP concept is central to economic CBA, particularly, to the valuation of non-timber benefits such as in valuing recreational sites, environmental quality, etc. (e.g. Price, 1989).

3.4.2. CBA valuation techniques

There are different CBA techniques for evaluating different forms of forest values and their advantages and disadvantages are summarised in Table 3.9. For traded or marketable forest products such as timber or rattan, market-priced or shadow-priced techniques are commonly used since these goods are traded in the market. The shadow-priced

Table 3.9 Some common valuation techniques in economic cost–benefit analysis and their advantages and disadvantages

Technique	Basis	Advantages	Disadvantages	Forest values
1. Shadow price	Use market prices but adjust for distortion	Reflects true economic value to society as a whole	Use of distributional weights may not be easy due to lack of data	Direct use (e.g. timber, rattan)
2. Market price	Use prevailing prices for goods and services traded in markets	In most cases, market prices reflect the private willingness to pay for consumption	Market imperfection or policy may distort market prices	Direct use
3. Cost-based	Use cost of replacing or restoring a damaged asset and uses this cost as a measure of the benefit	For some values, it is easier to measure the costs than the benefits	• Costs overstated or understated • Mis-matching of benefits between old and new locations	• Direct use • Indirect use (e.g. soil erosion, water, carbon)
4. Opportunity cost	The benefits of the activity causing environmental degradation are estimated to set a benchmark for what the environmental benefits would have to be for the development not to be worthwhile	Useful in evaluating subsistence benefits where harvesting and collecting time is a major input	May underestimate benefits significantly if there is substantial producer or consumer surplus	Direct use (e.g. medicinal plants)
5. Travel cost	Based on the assumption that the recreational value of a site is related to the travel cost	Easy to use	Need to incorporate a host of variables, e.g. personal time cost, travelling distance, etc.	Indirect use (e.g. recreation)
6. Hedonic pricing	Based on the assumption that the value of an asset may be determined by other factors (e.g. environmental quality)	Gives an alternate means of determining the value of benefits	Requires intensive and reliable data to develop the relationship	Indirect use (e.g. land cost)
7. Contingent valuation	Based on willingness to pay	• Direct approach • Wide applicability	Bias in approximation of value due to differing views	• Indirect • Option/existence (e.g. aesthetic)

Adapted from: Price, 1989; Pearce and Turner, 1990; Winnpeny, 1991, IIED, 1994 technique has its objective in correcting market distortion (Price, 1989). Alternatively, the replacement-cost technique can be applied which looks at the cost of replacing or restoring a damaged asset and uses this cost as a measure of the benefit of restoration. For non-market goods and services such as recreation, aesthetic value or water quality, these are more difficult to value because they do not enter markets. However, the attempt to evaluate such benefits in monetary terms is to give them an appropriate emphasis in comparing courses of action (Price, 1989). The travel cost method (TCM) can be used to estimate demand curves for recreation sites and the value of those sites. While the contingent valuation method (CVM) is based on expressed preference or willingness to pay for the enjoyment of a particular benefit and is used in valuing recreational sites (e.g. Price, 1989) or water quality (e.g. Desvoursges *et. al.*, 1987). The technique that is most often used in this study for evaluating the various forest values is the market price technique.

3.4.3. Importance of time

Forestry projects (e.g. reforestation) usually involve costs and benefits occurring over long periods of time. With the introduction of intertemporal effects comes the need to compare revenues and costs accruing at different times. The method to do this is either by discounting or compounding the flow of values. The formulae for the two are as follows:

Compounding... $$FV = P \times (1 + r)^t \qquad \text{......................} \; 3.1$$

Discounting ... $$PV = \frac{P}{(1+r)^t} \qquad \text{..........................} \; 3.2$$

where : FV = Future value
PV = present value
P = principal sum
r = interest rate
t = time

In practice, it is quite common to find that analysts apply discounting more than compounding in project evaluation. The rationale behind discounting is based on peoples' time preference to consume now, rather than later (Nautiyal, 1988). It assumes that individuals' consumption of utility will diminish over time. There are circumstances where this theory is not applicable but, overall, it forms the rationality of discounting. The second justification for discounting is related to the productivity of capital (Turner *et. al.*, 1994). The basic observation about capital is that one dollar's worth of resources now will generate more than a dollar's worth of goods and services in the future. Hence, an entrepreneur would be willing to pay more than one dollar in the future to acquire one dollar's worth of these resources now.

Since discounting attaches a lower weight to benefits and costs in the future, it has some unfortunate effects as far as the valuation of the environment is concerned and some of these issues are discussed in the following sections.

3.4.4. Problems with CBA

CBA is ambitious and all-embracing, attempting to aggregate costs and benefits of many kinds, to all people, in every generation (Price, 1989). This creates technical problems and the following are some of the issues surrounding CBA.

3.4.4.1. Discounting

The purpose of discounting in CBA is to give the present value of costs and benefits which have already been allocated to years. This enables the comparison of cash flows accruing at different times.

Because of the apparent discrimination against the future in discounting, this creates problems in its use in economic CBA dealing with long-term benefits and costs. When the environmental damage done by a project occurs far into the future, discounting will make the present value of such damage considerably smaller than the actual damage done (Turner *et. al.*, 1994). One contemporary example is the burning of fossil fuels by power utilities companies which emits greenhouse gases that cause global warming. When the distant damage-avoidance cost due to global warming is discounted, it will make the effect of global warming less significant. Where the benefits of a project accrue to 50 or 100 years hence, discounting will lower the value of such benefits and make it difficult to justify the project. An example might be afforestation project using trees that take a long time to mature.

While most economists accept discounting, other economists and different groups of social scientists either question it, or propose different discounting conventions. For example, Price (1989) gave two specific arguments against accepting individual time preference in social discounting. The first relates to perception of mortality where individuals would prefer to defer "consumption". The second is that individuals when taken by illness, in retrospect, wish they had forgone past consumption, in favour of consumption now (e.g. due to health reason). Price (1989: pp 313-315), however, cites six features of consumption (other than just pure time preference) which make them less valuable, into the future, and thus justify discounting namely; 1) the prospect of consumer elimination; 2) fashion; 3) technological advances; 4) the resource/population balance; 5) uncertainty and 6) choice.

There are also comments in the literature discrediting discounting due to opportunity-cost arguments. This concerns the issue of re-investment. The basis of discounting is that it is the reciprocal of compound interest. In turn, compound interest implies that if we invest one dollar today it will compound forward at a particular interest, provided the one dollar invested plus its interest earned is re-invested. If the interest or profit is consumed, this means that consumption flows have no opportunity cost (Price, 1993). This situation violates the assumption underlying the use of a constant discount rate which takes on a negative exponential curve.

3.4.4.2. Choice of discount rates

The choice of discount rate in forestry has caused enormous debate among economists because of its profound implications for the sustainable use of forest due to the long time-scale of forestry (Fisher and Krutilla, 1974; Pearce and Turner, 1990; Price, 1991; Markandya and Pearce, 1994). The application of high discount rates to forestry projects with a long cutting cycle would wipe out distant benefits, and could reduce environmental costs to insignificance even if they are grave or potentially disastrous (Winpenny, 1991). It has been argued that the appropriate rate for forest investments should be between the social and private rate of discount to address late costs, externalities, and intergenerational issues (Leslie, 1987; Nautiyal, 1988). The generally recommended rate falls between 2 and 4 % after adjusting for inflation (e.g. Leslie, 1987). Others (e.g. Winpenny, 1991), however, have objected to using the rate of discount as a tool for adjusting market imperfections, and have suggested that analysts should assign benefits and costs as accurately as possible to the respective years that costs and benefits are incurred (Winpenny, 1991). Recently, the use of a zero discount rate has been promoted which follows the underlying idea that the interests of future generations are not any less significant then those of the present generation (Leslie, 1987) or that in the future resources will be increasingly scarce and inadequate technological advance may not be sufficient to overcome this limitation (Price, 1990). The validity of a zero discount rate is, however, rejected by most economists as the majority favours some form of opportunity cost of capital as a public investment (although opportunity cost of capital does not necessarily imply discounting). This discussion implies that the choice of discount rate for economic CBA should be somewhere below the cost of capital; the latter may be between 8 and 12 %, although much higher rates are found in poor countries. The discussion about the choice of a discount rate is not settled.

An alternative to adjusting discount rates is to ensure that benefits and costs associated with a project are adequately identified and accounted by other means. Preferably, all costs and benefits should be expressed in real terms (after adjusting for inflation) to eliminate the need to forecast future changes in monetary values. Frankhauser (1995) suggested that analysts should also supplement their results with extensive sensitivity analyses since decisions about projects are made on the basis of assumptions about the future.

3.4.4.3. Distribution weights

The use of willingness-to-pay (WTP) in cost–benefit analysis is based on the *Pareto* concept that no one should be worse-off as a result of consumption or change. A statement on distributional equity, therefore, forms an integral part of CBA to reveal the extent to which the project redistributes its income to the affected parties. Weights are derived from several means, namely: dictated by governments, past government choices among projects, and mathematical relationship between income and its marginal utility (Price, 1989).

Distributional weights are not used in economic CBA because they separate efficiency from distributional objectives (Price, 1989). They are also seldom adopted in developing countries because most public projects are funded through the government which should take social dimensions into account. In this study, distributional equity is dealt with only by making a statement.

3.4.4.4. Non-market benefits

Environmental goods and services often have no markets in which they can be exchanged. The reasons for poor or non-existent markets are the difficulties in quantifying the output of products or projects (Nautiyal, 1988). This presents a problem, and a considerable amount of uncertainty can surround their true value and significance (Turner *et. al.,* 1994). Many of the environmental assets are also public goods which makes it difficult for markets to evolve. But it is generally recognised that the attempt to evaluate such benefits in monetary terms does give them an appropriate emphasis in comparing courses of action (Price, 1989).

3.4.5. Implementing CBA

The preparation of a cost–benefit analysis generally involves five main steps although other variations may exist because CBA is not a unified and agreed methodology (Price, 1989). The methodology used in this study in carrying out the CBA is as follow;

(1) identification of physical inputs associated with the project,
(2) estimation of prices for the inputs and the outputs,
(3) preparation of a cash flow table or streams,
(4) if cash flow extends into the future, the application of discounting or compounding to make costs and benefits comparable at a point in time,
(5) conducting a sensitivity analysis to address the effect of contentious figures in the appraisal.

When revenues and costs at different times are compared, a criterion of profitability is needed (Price, 1989). A profitability criterion must indicate: (a) whether an investment is profitable or not (the acceptability criterion); (b) how relatively profitable each of several incompatible or competing investments is (the selection criterion). The most common profitability criterion that are used in cost–benefit analysis are : (a) net present value (NPV), (b) internal rate of return (IRR), (c) pay-back period and (d) benefit-cost ratio (BCR).

These economic indicators of project-worth are used individually or in combination to answer different questions. To select among mutually exclusive projects such as alternative forest uses, the costs should be subtracted from the benefits and preference be given to the project or plan that promises the greatest net benefit as indicated by NPV. However, if the decision involves a number of potential independent projects which show expected benefits in excess of their costs, and budget limitations compel the decision-maker to select only the most advantageous, the benefit-cost ratio is the appropriate criterion (Pearse, 1993).

For this study, the efficiency or relative advantage of RIL and CL is expressed by the net present value (NPV) criterion. The NPV criterion is a suitable measure for this study because it provides a means of evaluating and comparing the benefits and costs of RIL and CL accruing at different times comparable at a point in time through discounting. The NPV of benefits and costs at time *t*, given discount rate *i*, is calculated by the following equation;

$$NPV = \sum_{t=0}^{n} \frac{Bp - Cp}{(1+i)^t}$$

where B*p* and C*p* = benefit and cost in year *t*
i = discount rate
t = time, year 0 to n
n = last year

On the basis that the RIL project costs were incurred at the private discount rate, it may, at first instance, seemed appropriate to discount at the opportunity cost of capital, i.e. the interest at which funds can be borrowed (Nautiyal, 1988). This approach, however, is more concerned with allocating capital funds for immediate visible benefits than for the overall long-term benefits to society to which both ICSB and NEES may be obligated by the nature of their businesses. The alternative is to use a discount rate that reflects both the private and social rate of discount (Nautiyal, 1988). Using this approach, Zakaria (1993) determined the real rate of return to be 2 % per annum for Malaysia. He obtained this rate based on the fixed deposit interest rate of commercial banks in Malaysia over a 15-year period from 1975 to 1990. There has not been any major change in this rate since 1990. This study will adopt a 2 % discount rate as the base-rate for the economic appraisal with alternative rates ranging from 2 to 10 % (at 2 % intervals) for decision makers in both the private and public sectors to form their own judgement about the viability of the RIL project being evaluated.

Since decisions about projects are made on the basis of assumptions about the future, these assumptions are commonly subject to sensitivity analysis to seek greater information about their impact on the project is worth.

3.5. Summary

This chapter has outlined the methodologies that were adopted for the ecological assessments in the field and for the economic assessment in this research project. The field assessments involved three different experimental designs: for timber and carbon a similar design was used whereas for rattan and soil there was a different design; the water and wildlife values were based on secondary data. In the timber and carbon analysis, growth models were adopted to predict future timber and biomass growth and mortality. Out of three models reviewed, two were chosen for this study. The *DIPSIM* model provides growth and yield forecasting for the evaluation of the timber benefit. For the carbon analysis, the *C-REC* model was chosen. A felling and skidding time and motion study was also carried out based on random sampling of work activity. The overall purpose of the ecological impact assessments of the various forest values was to provide the data inputs for the economic analysis. The method chosen to conduct the comparative economic assessment of RIL and CL techniques was based on cost–benefit analysis. CBA allows a wide range of forest values to be examined within the scope of this study. Because CBA is an all-embracing technique attempting to put all different values of costs and benefits into a single numararie, it has presented some technical problems. For example, the choice of discount rates and relevance of distribution weights have important bearings on the outcome of the analysis, especially involving a range of forest values. The essence of time is important in this thesis project because the forest values being examined have different harvests (e.g. timber involve two harvest cycles over 120 years in this study). With other forest values having different time frames, it is necessary to bring the different timing of costs and benefits to a comparable point in time. Discounting was adopted to meet this end and the choice of the discount rate holds the key to the final decision about whether RIL will replace CL techniques. The framework outlined in this chapter forms the basis for evaluating the economic analyses of the various forest values in the following chapters (chapter 4 to 9).

Chapter 4: Timber

4.1. Introduction

In this chapter, the costs and benefits of harvesting trees using RIL and CL techniques are evaluated and compared. RIL is designed to reduce logging damage by implementing additional operations of pre-felling climber cutting, tree markings for retention and directional felling, and intensive planning for skidding activities which are not practised in the conventional bulldozer harvesting system in Sabah, Malaysia. RIL techniques also adhere to a set of harvesting guidelines that include detailed specifications for road construction, stream crossing, skid trail width, numbers/location/size of log landing, and cross-drains.

With such a level of inputs and requirements for RIL techniques, RIL would be more expensive than CL techniques but it might still be economic if repeated in the next cut because of better residual stocking gained from reduction in logging damage. This hypothesis has been universally recognized either implicitly or explicitly in most studies concerning 'supervised' logging in tropical forests (e.g. Marn and Jonkers, 1982; Hendrison, 1990) and some even advocate that improved logging practices such as RIL would be cheaper (Hendrison, 1990). To test this hypothesis, the economic analysis covers one felling rotation of 60 years after which the second cut will be conducted (the first cut is at the start of year 1 [time=0 or t_0]) in order to capture the distant benefit of improved stocking. The 60-year rotation is the felling cycle adopted by RBJ in the management of its forest concession.

The economic implications of adopting RIL techniques in harvesting tropical trees from the viewpoint of a forest enterprise i.e. RBJ are discussed. Options to improve the economics of RIL techniques, hence its economic feasibility, are also presented. The discussion also explores funding from the international community for the promotion of sustainable forest practices.

4.2. Materials and methods

4.2.1. Types and source of data

The economic analysis used two types of data inputs (physical and financial) from different sources. The physical data requirements on timber species, forest structure, area logged, types of damage and amount of timber produced were sourced directly from the study area as described in Chapter 2. The financial data relating to log prices, log grade and logging costs were obtained from RBJ and from other sources.

4.2.2. Timber valuation procedures

4.2.2.1. Step 1: Compilation of logging impact data

The first step in the timber valuation procedures is the compilation of the plot data that were established within the study area for the purposes of describing the stand structure before and after logging; the extent of area logged by RIL and CL techniques; production estimates or harvest yields; and in assessing the extent and types of logging damages due to RIL and CL techniques. More importantly, this information provides the various assumptions that are required for the economic model in calculating the economics of the first harvest, and the second harvest at year 60 after first harvest. The methodology of data collection has been described in Chapter 3 (Section 3.2.1.1).

4.2.2.2. Step 2: Growth and yield projection

In order to investigate the economics of the second harvest scheduled at 60 years after the first cut, a growth and yield prediction of the logged-over RIL and CL units was conducted using the *DIPSIM* forest growth model (fuller description of *DIPSIM* was given in chapter 3). The model inputs are tree diameters, species, site quality and tree height. Among the four variables, tree size and species are suspected to have an effect on the simulated output, hence, the economic value of the final crop. The effects of these variables were not tested in a sensitivity analysis due to unavailable long-term data to validate the results of the tests. Only trees greater than 10 cm DBH taken from plots established in the study areas are required for the simulation. Trees below 10 cm DBH are recruited into the simulation process based on recruitment models built into the model (see Chapter 3 for details). The source of data for the growth modelling is from plots that were established in the two study areas. During data entry, trees with severe damaged (uprooted, missing or with crown snapped-off) were excluded from the model while those with minor to moderate damages (crown and stem damage) are included since their fate is still uncertain. The model outputs are summarized in stand (trees ha^{-1}) and stock (cubic metre ha^{-1}) tables and by diameter classes (10-20, 20-40, 40-60, >60 cm DBH). Timber species are differentiated into commercial and non-commercial groups based on their current marketability. Commercial timbers include the dipterocarps, non-dipterocarps and pioneer species that have market value. Non-commercial timber species include timbers which do not have market value up to the time of this study. The simulation results were presented in 20-year intervals to assist in understanding and describing the forest dynamics in the RIL and CL units.

4.2.2.3. Step 3: Estimating timber revenue

The main source of forest revenue for RBJ is the sales of saw- and veneer-logs from its forest concession. The revenue consideration for this study is therefore based on the sales of sawn- or veneer logs. In calculating the log revenue for the CL and RIL units, the harvest yield in these units and the log price are essential; the latter is also determined by the log size, species and quality (Price, 1989). The log revenue is expressed per cubic metre of timber harvested and for a hectare of forest based on harvest yields from CL and RIL units. The following sections outline the methods used to calculate the log revenues for CL and RIL units for the first and second harvest at years 0 and 60, respectively.

4.2.2.3.1. Log species, size, and quality

For the first harvest, the log revenue is derived from the actual harvest yield. The log production estimates are first summarised by species according to the commercial and non-commercial groups as explained in section 4.2.2.2. The summary list includes logs of 40-60 cm DBH even though the mandated diameter-cutting limit is 60 cm DBH. This exception arises because trees below the diameter-cutting limit can be harvested if they are found on the road right-of-way, log landings or have been knocked-down during felling (Forest Rules, 1969). Each log produced from the forest is given one of six quality classes based on its visible defects (see Appendix 2.1 for details) so that it can be priced accordingly. The log grades composition in the CL and RIL units was not available for this study because there was no tracking of log quality produced from the study areas. In the absence of primary log grade data specifically from the study areas, this information was sourced and compiled from within coupe YL2/93 containing the CL and RIL units and another coupe (YL2/94) located adjacent to coupe YL2/93. It is assumed that the environment (soil, temperature and rainfall) in YL2/94 is similar to that in the study area (CL and RIL units) since it is adjacent to each other and appeared the same, hence, the timber species composition would be similar and vulnerable to similar defects as manifested in the timber grades. The results are presented in Section 4.3.3.1. It is assumed that there is no difference in log grades between the RIL and CL units for the first as well as the second harvest.

For the second harvest, a slightly different treatment on the projected harvestable timber stock is necessary because the stand and stock tables represent *gross* estimates. In the first instance, not all trees in the 40-60 cm DBH class are harvested. Secondly, tree mortality and culls due to harvesting impacts were not predicted during the simulation run using *DIPSIM*, therefore, represent the gross volume. Hence, it is necessary to include only a proportion of trees in the 40-60 cm DBH and to exclude trees that suffered crown and stem damages. These effects are accounted by assigning a percentage deduction from the gross merchantable stock based on the harvest yield and mortality assessment results conducted 8-12 months after logging. Further deductions are also provided for culls due to tops, trimmings split ends, natural defects and inaccessible timbers. For this, a 30 % reduction was applied as recommended for Sabah (Bhargava and Kugan, 1988; Ong and Kleine, 1995). The deductions for mortality and culls are imposed on the projected stand and stock only at the end of the rotation. As in the first harvest, the log grades composition in the RIL and CL units was assumed to be same based on the log grades in logging coupes YL2/93 and YL2/94. Given the higher standard of hygiene (greater care) in harvesting trees using RIL, it can be expected that technical defects such as ring shakes and splits would be minimized; log freshness/ coloration would also be better in RIL. Consequently, the timber grades average in RIL units would be higher than in CL units. The potential improvement of timber grade for logs produced from RIL units was evaluated by increasing the SQ grades presented in the base case by 10 %, 30 % and 50 % with a corresponding decrease in the MQ grades. These grade categories are chosen because 40 to 60% of the timber in Sabah by volume would fall in the SQ grade and the price difference between these two grade categories is significant ranging from RM7-20 m^{-3} (ICSB, 1995).

4.2.2.3.2. Log price and outlook

The log price for this study is based on the Sabah Foundation's F.O.B. (free on board) log price, and is assumed to reflect the true market price. The 1993 log price is taken as the basis year for projecting the future price to be commensurate with the start of this study.

Log price projection is based on a study commissioned by the ITTO (1993). Three models were used in the study to analyse the trends and trade in the supply and demand of tropical timber in the Asia-Pacific region. These models are briefly described in the following:

- The *log supply model* is a combination of a simple growth-drain model of the natural production forest, and a land use accounting system that shifts land between production categories. It models the log production of up to six broad categories of forest types. Each type is classified (or reclassified) with respect to its log production potential as permanent production forest, state/conversion forest, plantations, estate crop plantation, other sources, or not available). The purpose of the model is to explore the implications with respect to log supply of alternative scenarios of land use and silvicultural practice.

- A *gap model* is used to describe the supply and demand situation for sawnwood, plywood/veneer and logs. Conversion factors are used to translate sawnwood and plywood/veneer consumption into roundwood equivalent. From this, the results from the model identify import and export surpluses and deficits in each country and for the region as a whole. The model utilised historical data for the period 1985 to 1991. Demand and supply is then projected to the year 2010. Supply projections are taken from the timber supply model. Econometric analysis and other forecasting methods (details given in the ITTO study) are used to describe the interactions between supply and demand trends as incorporated in the *market model*.

- The market model was originally developed by Zhang *et. al.*, (1992) known as the PELPS III (Price Endogenous Linear Programming System) which is a linear programming tool. The base data includes product and log consumption and production, prices, manufacturing costs, exchange rates, tariff rates and recovery rates. Prices for the exporting countries are based on F.O.B. port while the importing prices are C.F. (costs and freight) prices. The differences between these prices accounts for transportation costs, margins and handling costs. The final set of information required by the market model is the demand and supply elasticities. For the demand elasticities, the final products considered are sawnwood and plywood. Demand curves are not explicitly stated for logs as their demand is a derived demand generated by activity in the manufacturing entities. The demand equations and elasticities are estimated assuming cost minimization. Ordinary least squares was used to estimate the coefficients and elasticities. PELPS also allows specification of economic supply curves for the various factors of production (e.g. logs, labour, capital, energy, etc.) which are then combined with other manufacturing cost data and technical recovery factors to determine the product supply equation. For the ITTO study, the timber supply elasticities were taken from the studies reported in LEEC (1992), Vincent (1989) and Cardellichio *et. al.*, (1988).

4.2.2.3.3. Calculation of log revenue

The log revenues (in ringgit Malaysia) for the first and second harvests were calculated for a hectare of forest by assigning the merchantable yield according to its species groups and grade composition; then multiplying the respective yield in each grade by its corresponding FOB value. The revenue for each species is then summed and divided by the total merchantable volume (excluding non-commercial species) to obtain the average revenue per cubic metre for all species. The reason for using a weighted average revenue for all species is to simplify the analysis that involves many timber species. In the second harvest, the projected log price change is based on the ITTO's study on the trends and trade in the supply and demand of tropical timber in the Asia-Pacific region as described in section 4.2.2.3.2.

4.2.2.4. Step 4: Estimating forest operation costs

The fourth step is the compilation of the RIL and CL forest operation costs. This includes the cost of extraction, log royalty, timber rights, tug boat fees and operating overheads; hereinafter referred to as the cost of sales. The costing is expressed on a per hectare (RM ha^{-1}) and per cubic metre (RM m^{-3}) of area logged.

4.2.2.4.1. Extraction costs

One of the key components of the cost of sales is the cost of extracting timber (including felling) from the forest to the port of loading. The extraction costs are classified into pre-harvest operations (activities performed prior to harvest), harvest operations (activities performed during harvest operations), post-harvest operations (activities performed after harvest operation) and non-operational or supervision costs. Within these four classifications, there are cost items applicable only to RIL which are additional activities over CL techniques (e.g. cost of climber cutting; directional felling; skid trail planning etc.). These additional cost items are defined as the *RIL investment costs.* There are also cost items that are common to both RIL and CL techniques (e.g. coupe boundary survey, mapping, road construction etc) which are identified as the *standard costs*. The difference between RIL and CL standard costs due to lower harvest yield in RIL is the *RIL differential costs.*

The basis of calculating the extraction costs in the pre-, during and post-harvest operations depends on the mode of payment. For example, the pre- and post-harvesting operations costs are paid per unit area and the per cubic metre equivalent is obtained by dividing the yield in that hectare of forest. In the harvesting operations, road construction is paid based on per linear distance of constructed road and the equivalent cost per cubic metre is calculated by dividing the total cost of road construction in a hectare by the production per cubic metre in that hectare of forest. Log extraction activities need no conversion because they are paid based on the volume produced in a hectare of forest.

The extraction costs presented in this study included *fixed* costs (costs which accumulate with the passage of time, rather than with the rate of work e.g. interest on investment, taxes and insurance); *operating* costs (costs that vary with the rate of work e.g. costs of fuel, lubricants, tyres, equipment maintenance and repairs), and *labour* costs (costs that are associated with employing labour, including direct wages, social costs etc.). Three assumptions are made with regard to the extraction costs computation.

First, it is assumed in this analysis that the fixed costs (on a per hour basis) do not differ between RIL and CL techniques on the basis that the machines employed to extract timber belong to the same logging contractor and are purchased at nearly at the same time. Although machine cost has traditionally been depreciated at a fixed percentage of its value annually whether the machine is working or not, this accounting approach of machine costing has been challenged by Price (1989) who argued that the cost of machinery would vary with the rate of working. Price's (1989) approach could have significant saving where machine idle time is high but the lack of machine cost data did not permit the use of Price's method in this study. The second assumption is that the logging crews were employed by the same contractor, even though different sets of crews were assigned to carry out the two logging techniques. Thirdly, it is assumed that the road construction costs in the RIL and CL units are the same because the roads in RIL and CL units were constructed with the same specifications.

The felling and skidding costs between RIL and CL techniques were expected to differ because RIL focuses on reducing incidental damages by improving the felling and skidding operations. To verify this, a time and motion study was conducted to investigate the felling and skidding time and the results incorporated into the costing analysis. Details of the research method for the time and motion studies are given in Chapter 3 and the results presented in Section 4.3.4 of this Chapter.

For the second harvest, the extraction costs were assumed to change based on the average annual rate of change in real prices charged by producers in Malaysia over the period 1983-1993 as reported in the Malaysian Producer Price Index (MPPI; Department of Statistics, Malaysia, 1993). The MPPI measures the real price changes from 1989 (base year) using the Laspeyres index for ten groups of commodities classified according to the Standard International Trade Classification System based on the type of material and use of the commodity. The ten groups of commodities are : (1) food and live animals; (2) beverages and tobacco; (3) crude materials (inedible); (4) mineral fuels, lubricants and related materials; (5) animal and vegetable oils and fats; (6) chemicals and related products; (7) manufactured goods (material); (8) machinery and transport equipment; (9) miscellaneous manufactured articles, and (10) commercial and transport not classified elsewhere. The MPPI covers about 1,800 establishments and collects some 5,300 price quotations for 1,400 commodities. For this study, the MPPI of imported machinery and transport equipment is used since a large part of the logging costs cover this cost item. The MPPI for this grouping averages a real price increase of 2 % per annum over the period 1983-1993 (Department of Statistics, Malaysia, 1993).

4.2.2.4.2. Log royalty

Log royalty represents the resource fee payable to the Government per cubic metre of timber sold. Although it is a transfer or benefit to the government, it is considered as cost to RBJ since it is a payment incurred. For this study, the local processing royalty rate (flat-rate of RM40 m^{-3} for all timber species) is adopted for both CL and RIL because of the log export ban enforced since 1993. This study assumes that the rate remains for the second harvest since this is a policy decision which is unpredictable in nature.

4.2.2.4.3. Timber rights

By an agreement, RBJ pays the Sabah Foundation a fee for the right to harvest timber from the Sabah Foundation forest concession. The fee is computed based on the stumpage value of standing timber for the whole forest concession and amortized over the 100-year Timber Licence Agreement. The fee also represents transfer or benefit to the receiving agency (i.e. the Sabah Foundation) but is considered a cost to RBJ in this study since it is an expenditure item. For the CL, the fee is calculated from a three-year average (1992-1994) based on RBJ's actual expenditure and timber volume produced over this period. This method is adopted because primary data for timber rights is not available for the CL and RIL units.

It is anticipated that the harvest yield from RIL units will be lower than the CL units. This means that the unit cost on timber right fee will be higher for RIL. In the absence of actual data on the quantum of timber right fee for the RIL area (and CL which uses historical data), to calculate the actual unit cost per production, the increase in cost in RIL is determined by a relationship of harvest yield per m^3 between CL and RIL units. This assumes that there is a linear relationship between cost and production. For example: if CL's timber right fee is RM5 m^{-3}; harvest yields for CL and RIL are 100 m^3 ha^{-1} and 50 m^3 ha^{-1}, respectively. RIL's timber right fee is RM10 m^{-3} calculated by multiplying RM5 m^{-3} with the correction factor of 100 m^3 ha^{-1} divided by 50 m^3 ha^{-1}, represented by (RIL_{yield}/CL_{yield}). This study also assumes that the fee does not change in the second harvest because it is a policy matter that is difficult to predict change.

4.2.2.4.4. Tug boat fees

RBJ hires contractors to tow log rafts from the log pond to the mills or shipside on a piece-meal basis (per cubic metre). For CL, this is computed based on the RBJ's actual expenditure and timber volume produced over this period for a three-year average (1992-1994). This method is adopted because primary data is not available for the CL and RIL units. Tug boat fees for RIL is the same as CL because payment is made per cubic metre of timber loaded. The second harvest assumes that tug boat fees for the CL and RIL units will rise in real price at 2 % per annum (Malaysian Producers' price index,1993).

4.2.2.4.5. Operating overheads

RBJ's overheads include general and administration costs, remuneration and allowances for forest workers; financial charges, management fees and interest charged on the timber rights calculated based on the stumpage value. The source of these cost inputs for the CL is the mean value of the three-year (1992-1994) actual expenditure incurred by RBJ because actual data are not available. For RIL, the operating overheads were calculated by multiplying the CL's overhead by the ratio of the harvest yields between CL and RIL units (CL_{yield}/RIL_{yield}). The CL_{yield}/RIL_{yield} factor is to account for the lower timber production in RIL units. For the second harvest, the operating overheads in both units will rise at 2 % per annum based on the real price increase recorded in the Malaysian Producers' price index (1993).

4.2.2.5. Step 5: Benefits and costs evaluation

The benefits and costs of producing timber using RIL and CL techniques for one felling rotation of 60 years were investigated under interest rates of zero (no discounting) to 10 %. The range of discount rates would allow decision makers in both the private and public sectors to form their own judgement about the viability of the project being evaluated. This study, however, considers 2 % as the base rate for decisions and this rate represents the private and social rate of discount for Malaysia (Zakaria, 1993).

A sensitivity analysis on log price, timber grades and extraction costs was carried out. Log price and extraction costs have significant impact on the benefit-cost evaluation because they are key factors in determining the profit margin. Timber grades have an impact on the analysis because they are one of the determinants of log prices. Furthermore, there is a likelihood that RIL could potentially yield better log quality through the care required for timber fellers and bulldozer operators in handling logs resulting in lesser physical damage to a log.

4.2.3. Economic scenarios

The basic economic scenario presented in this study is one in which the timber harvesting methods in the first harvest will be adopted in the second harvest in the two study areas i.e. areas logged by RIL and CL techniques at year 1 (time = 0) are logged by same techniques at year 60. However, it is very likely that harvesting practices in the future will be aligned to RIL techniques given present global emphasis vis-à-vis the ITTO 2000 objective in bringing tropical forest to sustainable status (i.e. areas logged by RIL and CL techniques at year 1 will be logged by RIL techniques at year 60). A third or worst scenario would be that present CL harvesting techniques are maintained which is unlikely as Malaysia has subscribed to the principle of sustainable forest management and development. The implications of the second and third scenarios are discussed in the final analysis without rigorous cost-benefit analysis.

4.3. Results and discussion

4.3.1. Logging impacts

4.3.1.1. Area logged

The total area including riparian reserves for the CL and RIL units was 184 ha and 264 ha, respectively. Riparian reserves (which are not logged) in CL and RIL covered about 8 ha and 34 ha, respectively; or 4 % and 13 % of the total study areas (Table 4.1). The greater proportion of riparian reserve in RIL was due to chance rather than the RIL prescription.

Within the RIL and CL logging units, approximately 76 % of the area was below 35° slope. Areas with slope over 35° in the two treatment areas were not significantly different ($mean_{RIL}$=27°, $mean_{CL}$=21°, *Wilcoxon* signed rank test P=0.1, N=4; Figure 4.1).

In the four CL units, almost all of the 176 ha was logged except in the riparian reserves (Table 4.1). This meant that all of the 47 ha or 27 % of the area with slope over 35° was logged.

Of the 230 ha available for logging in the RIL units, only 129 ha (56 %) was logged leaving 101 ha (44 %) unlogged. The unlogged portion in the RIL units falls on steep areas beyond 35° (although 17 ha out of 47 ha was logged) and in below 35° mainly due to RIL-imposed logging restrictions along stream and road buffer zones; enclaves; restriction of side-cutting on slopes greater than 20° which denied access to enclaves of loggable areas; and logging prohibition in pockets of stands where it would cause adverse environmental impacts (Category 2.3 in Table 4.1). The unlogged portion within the steep areas represented 13 % of the total area compared to only less than 1 % in the CL areas. On the other hand, the unlogged portion in slope below 35° constituted approximately 30 % of the total logging area (230 ha) for RIL while no such unlogged areas existed in the CL units.

Table 4.1 Area logged and unlogged in the RIL and CL units

	CL		RIL	
	Area (ha)	Percentage*	Area (ha)	Percentage*
1. Riparian reserve	7.7		33.7	
1 Logged	0.0		0.0	
2. Logging area (ha)				
2.1 Total logging area	176.0		230.0	
a slope <= 35 deg	128.0	72.7	180.7	78.6
b slope >= 35 deg	48.0	27.3	47.1	20.5
c Buffers and enclaves	0.0	0.0	2.2	1.0
2.2 Area logged	175.0	99.4	129.0	56.1
a slope <= 35 deg	128.0	72.7	112.0	48.7
b slope >= 35 deg	47.0	26.7	17.0	7.4
2.3 Balance unlogged area	1.0	0.6	98.8	43.0
a slope <= 35 deg	0.0	0.0	68.7	29.9
b slope >= 35 deg	1.0	0.6	30.1	13.1
c Rocky area				
3 Total of 1.1 and 2.1	183.7		263.7	

* Percentage area is calculated based on area for logging in Category 2 only and excludes category 1 which is prohibited from logging under the Forest Rules 1969. The greater proportion of riparian reserve in RIL is due to chance and not because of the RIL harvesting guidelines

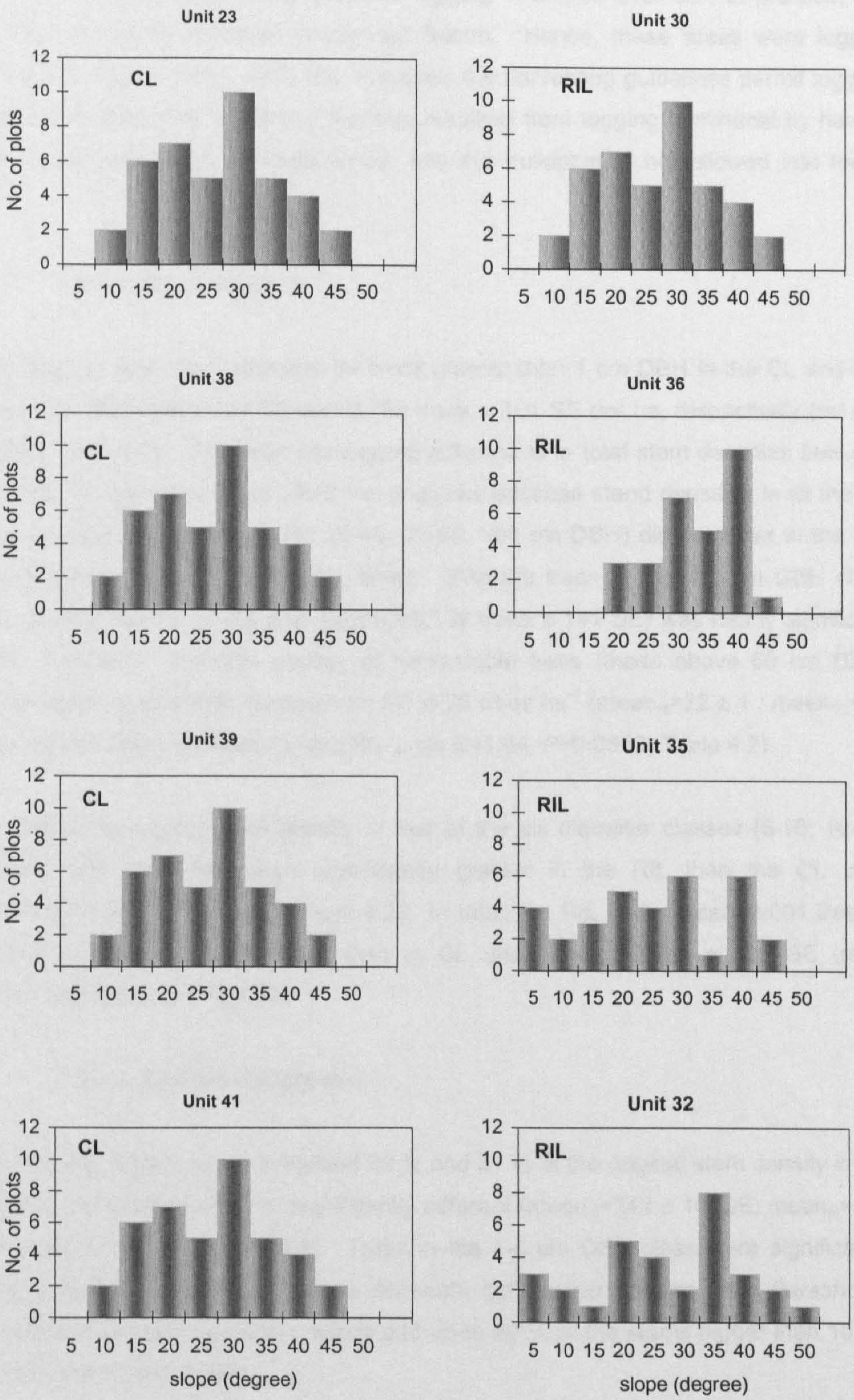


Figure 4.1 Slope frequency (no. of plots) in the CL and RIL units

Although the forest policy prohibits logging in slopes over 35°, in practice, the policy was not strictly enforced throughout Sabah. Hence, these areas were logged within the RIL and CL units. With RIL, however, the harvesting guidelines permit logging in these areas only when incidental damage resulting from logging is minimal by having the tree crown falling out of these areas, and the bulldozer is not allowed into these areas.

4.3.1.2. Stand structure

Prior to logging, total stem densities for trees greater than 1 cm DBH in the CL and RIL areas were 4,382 trees ± 212 SE and 3,798 trees ± 101 SE per ha, respectively (t=1.99, P=0.0936; Table 4.2). The large pre-logging differences in total stem densities between the RIL and CL plots would not affect the analyses because stand densities in all the six diameter classes (1-5; 5-10; 10-20; 20-40; 40-60; >60 cm DBH) did not differ in the two treatment areas (t-test, P=0.37-0.85, N=4); although trees in the 1-5 cm DBH class ($mean_{RIL}$=2,623 tress ± 75 SE and $mean_{CL}$=3,159 trees ± 141 SE) was nearly significant (t=2.291, P=0.062). Average density of harvestable trees (those above 60 cm DBH) across all eight logging units ranged from 17 to 28 trees ha^{-1} ($mean_{ril}$=22 ± 1 ; $mean_{CL}$=22 ± 1) and did not differ between CL and RIL units (t=1.94, P=0.0852; Table 4.2).

Following logging, tree density in four of the six diameter classes (5-10; 10-20; 20-40 and >60 cm DBH) were significantly greater in the RIL than the CL units ($0.005<P<0.05$; N=4; Figure 4.2; Table 4.2). In total, the RIL units (mean=3,001 trees ± 209 SE) had 538 trees ha^{-1} more than in CL units (mean=2,463 ± 132 SE trees, difference significant at P=0.033).

4.3.1.3. Species composition

Prior to logging, dipterocarps comprised 36 % and 31 % of the original stem density in the CL and RIL units, which was not significantly different ($mean_{cl}$=742 ± 100SE, $mean_{ril}$=522 ± 69; t=2,402, P=0.053; Table 4.3). Trees in the 1-5 cm DBH class were significantly different (t=2.667, P=0.037). The two dominant dipterocarp species were *Parashorea tomentella* and *Shorea johorensis*, which add up to 20 % of the stems bigger than 10 cm DBH (Putz and Pinard, 1995).

After logging, the overall dipterocarp species composition in the two treatment areas was 33 % and 30 % in RIL and CL, respectively, and was not significantly different (t=1.253, P=0.257). Significant difference in species composition was found in the 1-5 cm DBH and greater than 60 cm DBH classes (Table 4.3).

Table 4.2 Stand density (trees ha^{-1}) before and after logging in CL and RIL units

Treatment	DBH	CL Mean	CL ±SE	RIL Mean	RIL ±SE	t-test of the difference
Before	>=60	22	1	22	1	(t=0.194,P=0.852)
	40-60	24	2	23	1	(t=-0.472,P=0.653)
	20-40	108	2	109	2	(t=-0.228,P=0.827)
	10-20	285	17	304	5	(t=-0.893,P=0.406)
	5-10	784	51	717	17	(t=0.974,P=0.367)
	1-5	3159	141	2623	75	(t=2.291,P=0.062)
	Total	4382	212	3798	101	(t=1.990,P=0.0936)
After	>=60	7	1	13	2	(t=-3.472,P=0.013)*
	40-60	17	3	21	2	(t=-1.346,P=0.227)
	20-40	66	5	99	8	(t=-3.527,P=0.012)*
	10-20	161	14	258	19	(t=-4.164,P=0.006)**
	5-10	395	36	554	42	(t=-2.875,P=0.028)*
	1-5	1817	74	2056	137	(t=-1.537,P=0.175)
	Total	2463	132	3001	209	(t=-2.751,P=0.033)*

*** P< 0.001; ** 0.001<P<0.01; * 0.01<P< 0.05

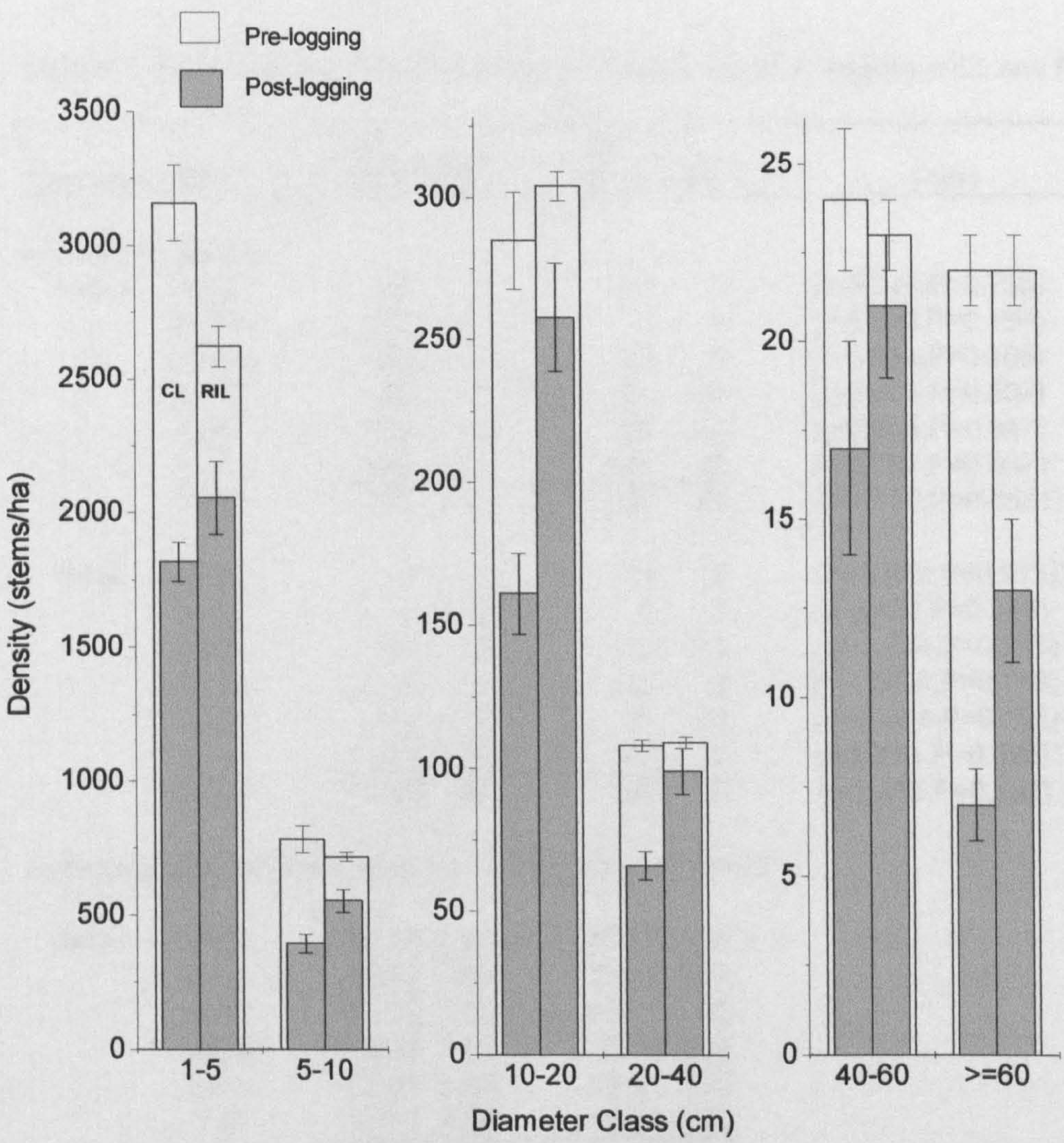


Figure 4.2 Density of trees over 1 cm DBH before and after loggging in units logged by CL (first column) and RIL (second column) techniques. The original stand structure in the experimental units did not differ significantly for the six DBH classes although for trees in the 1-5 cm DBH P=0.06 (t=2.291). After logging, there was a higher number of standing trees in the RIL units across all DBH classes. Tree densities in four of the DBH classes (5-10; 10-20; 20-40 and >60 cm DBH) were significantly greater in the RIL than the CL units

Table 4.3 Density of dipterocarps (trees ha^{-1}) before and after logging in CL and RIL units

Treatment	DBH	CL Mean	CL ±SE	RIL Mean	RIL ±SE	t-test
a) Absolute density						
Before	>=60	20	1	18	3	(t=0.347,P=0.739)
	40-60	12	2	9	1	(t=1.629,P=0.154)
	20-40	30	1	25	3	(t=1.904,P=0.105)
	10-20	43	5	51	10	(t=0.704,P=0.507)
	5-10	99	15	98	26	(t=0.068,P=0.947)
	1-5	538	77	321	28	(t=2.667,P=0.037)*
	Total	742	100	522	69	(t=2.402,P=0.0531)
After	>=60	5	1	10	2	(t=-3.482,P=0.013)*
	40-60	9	2	8	1	(t=0.533,P=0.613)
	20-40	20	2	23	3	(t=-1.024,P=0.345)
	10-20	23	6	41	9	(t=-1.660,P=0.148)
	5-10	47	6	81	22	(t=-1.514,P=0.181)
	1-5	331	34	225	12	(t=2.951,P=0.026)*
	Total	435	49	388	46	(t=1.253,P=0.257)
b) Relative density (Percent of stems in the original stand)						
Before	>=60	90.91	0.80	81.82	5.60	
	40-60	50.00	3.80	39.13	3.30	
	20-40	27.78	1.00	22.94	1.60	
	10-20	15.09	1.60	16.78	3.20	
	5-10	12.63	2.60	13.67	3.30	
	1-5	17.03	2.90	12.24	0.70	
	Mean	35.57	2.12	31.09	2.95	
After	>=60	71.43	1.80	76.92	7.40	
	40-60	52.94	2.50	38.10	3.40	
	20-40	30.30	1.50	23.23	1.50	
	10-20	14.29	2.20	15.89	3.60	
	5-10	11.90	2.20	14.62	3.70	
	1-5	18.22	2.00	10.94	0.90	
	Mean	33.18	2.03	29.95	3.42	

*** $P< 0.001$; ** $0.001<P<0.01$; * $0.01<P< 0.05$

In the CL units, density of lianes greater than 2 cm DBH averaged 586 stems ha^{-1} (SE=106, N=4) with about 86 % of the stems being less than 5 cm DBH. Sixty-seven percent of the climbers greater than 2 cm DBH found in the conventional logging units were killed during logging. This seems to contradict the reason for RIL, which assumes that most climbers survive CL and then become an infestation problem. However, assessing the mortality of lianes is a complex task given the time constraint for this study. Lianes density in the RIL units was not enumerated because they were removed prior to the start of data collection for the present study.

4.3.1.4. Removals

Logging reduced the original tree density (>1 cm DBH) by 44 % in the CL units but only 21 % in the RIL units (Table 4.4). This reduction includes trees that were extracted for commercial use as well as being destroyed in the form of uprooted, missing or crushed trees.

Fewer trees and less volume were harvested per hectare in the RIL units compared with the CL ones. The mean number of trees extracted for the CL and RIL units were 13 trees (± 1 SE) and 9 trees (± 2 SE) per hectare, respectively, and was significantly different (t=3.39, P=0.015; Table 4.5). The timber volume extracted from each individual unit ranged from 37 to 174 m^3 ha^{-1} and averaged 136 (± 15) and 106 (± 30) m^3 ha^{-1} in the CL and RIL units, respectively (Table 4.6; note the far greater variation between the RIL units). These volumes were measured at the log landings, and will differ from plot-based estimates (the latter reported in Pinard and Putz's (1996) for the same study). Trees in the 40-60 cm DBH removed from the units were in the range of 2-7 % of total volume produced and was not significantly different (t=0.885, P>0.425).

The density of trees uprooted during logging or missing from the post-logging enumeration for different reasons was higher in CL units (mean=37% ± 5% SE) than in RIL units (mean=13% ± 2% SE) for all DBH classes (Table 4.7a). The difference was highly significantly for trees below 40 cm DBH (0.003<P<0.025).

4.3.1.5. Condition of residual stands

In extracting 13 and 9 trees ha^{-1} containing a volume of 136 m^3 ha^{-1} and 106 m^3 ha^{-1} from the CL and RIL units, the proportion of trees greater than 10 cm DBH that were damaged represented 49 % and 24 % of the total remaining standing volume (Table 4.7b). For every cubic metre of wood extracted from the CL units, 0.71 m^3 of wood was damaged. Conversely, the volume damaged per cubic metre of wood extracted with RIL techniques was 0.50 m^3; approximately 30 % lower than with CL techniques. If only trees with fatal

Table 4.4 Summary of stand density (trees ha^{-1}) before and after logging in CL and RIL units

	DBH class							
	>=60	40-60	20-40	10-20	5-10	1-5	Total	(%)*
A) Conventional logging (CL)								
Pre-logging	**22**	**24**	**108**	**285**	**784**	**3159**	**4382**	**100**
Removals	**15**	**8**	**38**	**124**	**416**	**1319**	**1920**	**43.82**
a) Extracted	*13*	*1*	*0*	*0*	*0*	*0*	*14*	*0.32*
b) Destroyed (uprooted/missing)	*2*	*7*	*38*	*124*	*416*	*1319*	*1906*	*43.50*
Post-logging (residuals)	**7**	**17**	**66**	**161**	**395**	**1817**	**2463**	**56.21**
a) Crown snapped-off	*0*	*2*	*8*	*21*	*60*	*112*	*203*	*4.63*
b) Crown/stem Bark damage	*2*	*5*	*22*	*41*	*90*	*276*	*436*	*9.95*
c) Healthy individuals	*5*	*10*	*36*	*99*	*245*	*1429*	*1824*	*41.62*
B) Reduced-impact logging (RIL)								
Pre-logging (RIL)	**22**	**23**	**109**	**304**	**717**	**2623**	**3798**	**100**
Removals	**9**	**2**	**10**	**44**	**161**	**571**	**797**	**20.98**
a) Extracted	*9*	*1*	*0*	*0*	*0*	*0*	*10*	*0.26*
b) Destroyed (uprooted/missing)	*0*	*1*	*10*	*44*	*161*	*571*	*787*	*20.72*
Post-logging (residuals)	**13**	**21**	**99**	**258**	**554**	**2056**	**3001**	**79.02**
a) Crown snapped-off	*1*	*1*	*6*	*14*	*35*	*92*	*149*	*3.92*
b) Crown/stem bark damage	*3*	*2*	*17*	*26*	*47*	*322*	*417*	*10.98*
c) Healthy individuals	*9*	*18*	*76*	*218*	*472*	*1642*	*2435*	*64.11*

* Percentage of pre-logging stand density

Table 4.5 Number and volume of trees over 40 cm DBH extracted per hectare from CL and RIL units

Variable	DBH	CL Mean	CL ±SE	RIL Mean	RIL ±SE	t-test
trees ha^{-1}	>=60	13	1	9	2	(t=-3.388,P=0.015)*
	40-60	1	0.3	0.2	0.16	(t=2.028,P=0.089)
	Total >40	14	1.3	9.2	2.16	
Volume (m^3)	> 40	136	15	106	30	(t=0.885,P=0.425)

*** P< 0.001; ** 0.001<P<0.01; * 0.01<P< 0.05

Table 4.6 Timber production from the CL and RIL units

Unit	Area (ha)		Total production		Vol. yield (m^3 ha^{-1})	
	Total (Gross)	Logged (Net)	Number of Logs	Vol (m^3)	Gross	Net
CL23	41.5	41.5	640	4472	107.76	107.76
CL38	37.1	37.1	744	5316	143.29	143.29
CL39	50.0	50.0	842	6009	120.18	120.18
CL41	46.4	46.4	1083	8073	173.99	173.99
Total	175	175	3309	23870	545.21	545.21
Mean	--	--	--	--	136.30	136.30
RIL30	67.4	36.9	--	6389	94.79	173.14
RIL32	47.7	24.6	--	1904	39.92	77.40
RIL35	57.4	44.3	--	6118	106.59	138.10
RIL36	57.5	23	--	852	14.82	37.04
Total	230	128.8	--	15263	256.11	425.69
Mean	--	--	--	--	64.03	106.42

Note: These timber volumes were recorded at the log landings and not from the growth and yield plots. Data on the number of logs was not available for the RIL units.

Table 4.7a Occurrence of damaged trees (including both live and dead trees) after logging in the CL and RIL units

Variable	DBH	CL Mean	CL ±SE	RIL Mean	RIL ±SE	t-test
a) Trees uprooted, missing, or crushed.						
Trees/ha	>=60	2	1	0	0	(t=1.558,P=0.222)
	40-60	7	2	1	1	(t=2.955,P=0.059)
	20-40	38	5	10	2	(t=6.632,P=0.007)**
	10-20	124	18	44	6	(t=4.185,P=0.025)*
	5-10	416	47	161	17	(t=8.638,P=0.003)**
	1-5	1319	142	571	66	(t=9.298,P=0.003)**
	Total	1906	215	788	93	(t=10.617,P=0.002)**
Percentage	>=60	19.85	7.00	1.72	1.60	
of original	40-60	28.35	7.50	6.21	2.30	
stand	20-40	35.01	4.70	9.30	2.10	
(excluding	10-20	43.55	4.70	14.53	2.40	
harvested	5-10	53.06	2.20	22.43	2.00	
trees)	1-5	41.75	3.20	21.77	1.40	
	Mean	36.93	4.88	12.66	1.97	
b) Trees with crown snapped-off.						
Trees/ha	>=60	0	0	1	0	(t=-0.538,P=0.609)
	40-60	2	1	1	0	(t=0.789,P=0.459)
	20-40	8	0	6	1	(t=0.654,P=0.537)
	10-20	21	3	14	3	(t=1.681,P=0.144)
	5-10	60	11	35	16	(t=0.774,P=0.468)
	1-5	112	23	92	14	(t=0.316,P=0.763)
	Total	203	40	149	34	(t=0.817,P=0.445)
Percentage	>=60	4.44	2.40	4.58	1.80	
of original	40-60	8.33	5.10	5.82	0.90	
stand	20-40	7.41	0.40	5.50	1.00	
(excluding	10-20	7.37	1.30	4.54	1.00	
harvested	5-10	7.65	1.70	4.91	2.10	
trees)	1-5	3.55	0.70	3.51	0.40	
	Mean	6.46	1.93	4.81	1.20	
c) Trees with crown and trunk bark damage.						
Trees/ha	>=60	2	0	3	1	(t=-0.611,P=0.563)
	40-60	5	0	2	1	(t=2.075,P=0.083)
	20-40	22	1	17	2	(t=0.802,P=0.453)
	10-20	41	11	26	4	(t=1.856,P=0.113)
	5-10	90	10	47	4	(t=5.042,P=0.002)**
	1-5	276	114	322	92	(t=-0.153,P=0.883)
	Total	436	136	417	104	(t=0.367,P=0.726)
Percentage	>=60	22.22	1.10	23.08	4.60	
of original	40-60	20.83	1.10	8.70	4.00	
stand	20-40	20.37	1.20	15.60	3.40	
(excluding	10-20	14.39	3.70	8.55	1.70	
harvested	5-10	11.48	1.50	6.56	0.50	
trees)	1-5	8.74	3.30	12.28	3.70	
	Mean	16.34	1.98	12.46	2.98	

*** P< 0.001; ** 0.001<P<0.01; * 0.01<P< 0.05

Table 4.7b Ratio of volume damaged per volume extracted for trees greater than 10 cm DBH (values in cells show the mean volume per ha and standard errors (bracketed))

	Conventional logging (CL)										Reduced impact logging (RIL)									
	10-20		20-40		40-60		>60		Total		10-20		20-40		40-60		>60		Total	
(A) Total volume	22	(1.34)	50	(1.35)	52	(1.34)	231	(18.20)	333	(26.55)	24	(1.46)	48	(3.0)	49	(3.85)	228	(35.11)	326	(43)
(B) Volume damaged	14	(1.43)	30	(0.68)	28	(4.56)	39	(13.52)	97	(20.19)	7	(0.89)	15	(2.92)	10	(3.35)	26	(5.20)	51	(12.36)
C.1 Fatal*	9	(2)	17	(5)	12	(4)	22	(13)	50	(22)	3	(1)	4	(1)	3	(2)	1	(1)	8	(4)
C.2 Non-fatal**	5	-	13	-	16	-	17	-	47		4		11		7		25		43	
(C) Volume extracted	0	-	0	-	2	(0.87)	134	(9.18)	136	(10.06)	0	-	0	-	0.67	(0.67)	103	(24.99)	103	(25.67)
(D) Ratio																				
B/(A-C)	0.64		0.60		0.56		0.40		0.49		0.29		0.31		0.21		0.21		0.23	
C/A	0		0		0.038		0.58		0.41		0		0		0.014		0.45		0.32	
B/C	0		0		14.0		0.29		0.71		0		0		14.93		0.25		0.50	
C.1/C	-		-		6		0.16		0.37		-		0.083		4.478		0.01		0.08	
C.2/C	-		-		8		0.13		0.35		-		-		10.45		0.24		0.42	

* Fatal damages include trees that are destroyed, killed or missing

** Non-fatal damages include stem, bark, bole damage not likely to kill the tree damage (destroyed and missing) were considered, the volume damage per volume extracted for the CL and RIL units were 0.37 and 0.08, respectively.

The proportion of the original number of stems greater than 1 cm DBH (excluding extracted trees) that suffered crowns snapped-off was higher in CL (mean=6% ± 2% SE) than in RIL units (mean=5% ± 1.2% SE), but was not significantly different in all diameter classes (t=0.817, P=0.445; Table 4.7a).

Crown and trunk (bark) damage were also higher in the CL units (mean=16% ± 2 SE) than in the RIL units (12% ± 3 SE) for all diameter classes, but only trees in the 5-10 cm DBH class showed a significant difference in this damage category (t=5.042, P=0.002; Table 4.7).

The proportion of undamaged stems in the CL and RIL units was 40 % and 70 % of their original total stems, respectively, and their mean totals were nearly significantly different ($mean_{CL}$=1,824 ±117SE, $mean_{RIL}$=2,435 ± 296SE; t=2.054, P=0.085; Table 4.8).

Tree condition was assessed in each plot at a time between 8 and 12 months after logging. The proportion of standing trees above 1 cm DBH that were dead (based on the number of live trees at the beginning of the period) in the CL and RIL units was 2.5 % and 1.5 %, respectively (Table 4.9). These trees died largely because of damage (snapped-off, crown and stem) inflicted during logging. The number of trees found dead in the 5-10 and 20-40 cm DBH classes were significantly different between treatments. The proportion of dead trees in the 40-60 cm DBH class in RIL and CL units were 1 % and 4 %, respectively. The proportion of trees greater than 60 cm DBH that were dead after logging in RIL and CL units were 4 % and 2 %, respectively. One explanation for the higher damage in the RIL units could be that the timber fellers were learning the skills of directional felling, hence, introduce additional damage in the early phase of training.

4.3.1.6. Forgone timber

With 101 ha out of the 230 ha in RIL units left unlogged due to compliance with the RIL harvesting guidelines, there were standing timbers considered forgone. There is an opportunity cost for these forgone timbers because they cannot be replaced from within or outside the Sabah Foundation forest concession due to restriction on the annual allowable cut based on area control. It is also too costly at present to use alternative harvesting systems to extract these forgone timbers (e.g. helicopter logging or skyline).

The total volume of harvestable standing trees in the 230 ha RIL units based on a 100 % inventory comprised 31,280 m^3 or 136 m^3 ha^{-1} (Table 4.10). The actual tree

Table 4.8 Density of undamaged trees between treatments after logging

Variable	DBH	CL Mean	CL ±SE	RIL Mean	RIL ±SE	t-test
Density (stems/ha)	>=60	5	0	9	1	(t=-5.792,P=0.001)**
	40-60	10	1	18	3	(t=-1.386,P=0.215)
	20-40	36	3	76	17	(t=-1.255,P=0.255)
	10-20	99	4	218	53	(t=-1.624,P=0.156)
	5-10	245	27	472	104	(t=-0.774,P=0.469)
	1-5	1429	83	1642	119	(t=-1.674,P=0.145)
	Total	1824	117	2435	296	(t=-2.054,P=0.085)
Percentage of original stand (excluding harvested trees)	>=60	55.56	5.60	69.23	3.50	
	40-60	41.67	3.20	78.26	5.70	
	20-40	33.33	0.50	69.72	5.70	
	10-20	34.74	0.90	71.71	4.00	
	5-10	31.25	1.00	65.83	3.40	
	1-5	45.24	3.40	62.60	3.40	
	Mean	40.30	2.43	69.56	4.28	

*** P< 0.001; ** 0.001<P<0.01; * 0.01<P< 0.05

Table 4.9 Mean number and proportion (%) of standing trees that were dead at a time between 8 and 12 months after logging

Variable	DBH	CL Mean	CL ±SE	RIL Mean	RIL ±SE	t-test
Percentage	>=60	0.18	0.01	0.16	0.03	(t=0.158, P>0.88)
	40-60	0.95	0.03	0.83	0.01	(t=0.301, P=0.778)
	20-40	3.6	0.07	0.75	0.05	(t=2.870, P=0.0349)*
	10-20	7.47	0.02	3.69	0.03	(t=4.384, P=0.005)*
	5-10	12.03	0.04	6.13	0.04	(t=1.047, =0.335)
	1-5	50.33	0.02	18.93	0.03	(t=2.144, P=0.085)
	Mean					
Percentage of original stand excluding harvested trees	>=60	2.00	0.70	1.00	1.00	
	40-60	4.00	2.10	4.00	1.00	
	20-40	3.00	0.80	1.00	0.60	
	10-20	3.00	0.10	1.00	0.20	
	5-10	1.00	0.40	1.00	0.50	
	1-5	2.00	0.30	1.00	0.60	
	Mean	2.50	0.73	1.50	0.65	

*** P< 0.001; ** 0.001<P<0.01; * 0.01<P< 0.05

Table 4.10 Timber forgone in RIL units

Logging	Trees enumerated		Trees felled		Timber forgone	
Unit	Stem no.	Volume (m^3)	Stems no.	Volume (m^3)	Stems no.	Volume (m^3)
30	928	9 280	567	6 389	361	2 891
32	667	6 670	198	1 904	469	4 766
35	899	8 990	519	6 118	380	2 872
36	634	6 340	79	852	555	5 488
Total	3 128	31 280	1 363	15 263	1 765	16 017

Source: ICSB, 1994 The calculation of volume assumes that the mean volume per tree in each unit was 10 m^3

volume harvested over 129 ha was only 15,263 m^3 yielding 118 m^3 ha^{-1} (note: log volume harvested was 106 m^3 ha^{-1}). The tree volume forgone in RIL was 16,017 m^3 equivalent to 70 m^3 ha^{-1} (16,017 m^3 divided by 230 ha). However, not all of this forgone timber in the RIL units can be harvested because of steep and rocky slopes, inaccessibility, waste and cull (although the CL units in Table 4.1 showed that all area was harvested other than the riparian reserve). Using a 50 % recovery factor, the forgone volume in the RIL units would be 35 m^3 ha^{-1}. The 50 % discount factor is applied to all pre-felling inventory estimates collected by RBJ as a matter of policy to arrive at the net harvest yield. This discount factor is derived based on an extensive comparison of actual versus production estimates from the forest concession.

4.3.1.7. Summary

Of the 176 ha allocated to the CL units for logging, almost all of the area was logged. In RIL units, only 129 ha (56 %) out of the 230 ha was logged leaving 101 ha (44 %) unlogged. The unlogged areas in RIL units was mostly RIL-imposed except for the 35° maximum slope which can not be logged as provided in the Sabah Forestry Department rules (1968). However, the 35° slope policy was not strictly enforced throughout Sabah. Within the RIL and CL units, these areas were logged but the RIL harvesting guideline permits logging in these areas only when incidental damage is minimal by having the tree crown falling out of these zones. Approximately 36 % out of 47 ha with slope over the 35° were logged in the RIL units.

The forest structure in the study area prior to logging (trees greater than 10 cm DBH) was representative of primary hill dipterocarp forests in Sabah (Table 4.11). Its diameter distribution exhibited an inverse J-shape (approximately negative exponential curve) with a higher stem density in the smaller classes diminishing as tree size increases. The stand density of 439 m^3 ha^{-1} is comparable to the stocking reported elsewhere in Sabah (Table 4.12). The average stand density for trees greater than 60 cm DBH at 22 trees ha^{-1} also approximates the values reported elsewhere in Sabah (Table 4.11). The density of dipterocarps in the study area prior to felling was within the range of 27-40 % as reported for other areas in Sabah (Newberry *et. al.*, 1992; Garcia and Goh, 1995). The density of dipterocarps post-logging was also similar to other findings reported by Chiew and Garcia (1988) and Udarbe (1995) at 27 %.

The mean volume of timber extracted in the CL and RIL units was within the extraction intensity of 40 to 160 m^3 ha^{-1} reported in other parts of the Sabah Foundation forest concession (ICSB, 1995). Such a level of extraction intensities is also found elsewhere in Sabah (Fox, 1968; Chai and Udarbe, 1977; Marns and Jonkers, 1981; Table 4.13). In comparison with other selectively logged tropical forests, the amount of timber

Table 4.11 Tree density in primary hill dipterocarp forests in Sabah

Location	Number per DBH class per hectare						Total
	10-20	20-30	30-40	40-50	50-60	>60	
[1]Sook Plain, Sabah	208	69	32	24	16	20	369
[2]Kuamut F.R., Sandakan, Sabah	143	70	25	22	9	18	287
	10-15	15-25	25-35	35-45	45-55	>55	
[3]Gunung Rara F.R. Tawau, Sabah	223	72	35	23	10	18	381
	10-32	>32					
[4]Ulu Segama F.R., Lahad Datu, Sabah	407	63					470
	10-20	20-40	40-60	>60			
[5]Ulu Segama F.R., Lahad Datu, Sabah	285	108	24	22			439

1-Liew and Juin, 1976; 2-Chiew and Garcia, 1988; 3-Garcia and Goh, 1995; 4-Newberry *et al.*, 1992; 5-This study, 1995

Table 4.12 Total tree density, basal area and volume in primary hill dipterocarp forests in Sabah

Location	Density N ha^{-1}	Basal area m^2 ha^{-1}	Volume m^3 ha^{-1}	Reference
Gunung Rara, Sabah, Malaysia	392	28.3	395.8	Garcia, 1995
Kuamut F.R., Tawau, Sabah	476	26.62		Chiew and Garcia, 1988
Ulu Segama F.R., Lahad Datu, Sabah	431	42.8	-	Kamarudin, 1986
Ulu Segama F.R., Lahad Datu, Sabah	470	26.3	-	Newberry *et. al.*, 1992
Ulu Segama F.R., Lahad Datu, Sabah	439	27.5	352.6	This study, 1995

Table 4.13 Log extraction intensity in primary tropical forests

Location	Volume ($m^3 ha^{-1}$)	References
Kalabakan F.R., Sandakan, Sabah	80	Chiew and Garcia, 1988
Ulu Segama F.R., Lahad Datu, Sabah	70-120	Marsh and Greer, 1992
Ulu Segama F.R., Lahad Datu, Sabah	54-175	This study, 1995
Pahang, Peninsula Malaysia	60-65	Abdul Rahshid and Shamsudin, 1992
Berau, East Kalimantan	9-247	Sist *et. al.*, 1998
Paragominas, Brazil	30	Johns, *et. al.*, 1996
Philippines	72	Ludwig, 1992
Suriname	20-30	Hendrison, 1990

extracted from the study area was relatively high even though the forests types and the lack of standard methodologies precludes direct comparisons of results. First cuts in Amazonian moist forest generally take less than 50 m^3 ha^{-1} (Uhl and Viera, 1989; Thiollay 1992; Verissimo *et. al.*, 1992); in African forests generally less than 30 m^3 ha^{-1} of timber is harvested (Wilkie *et. al.*, 1992; White, 1994). The trees that were harvested include those in the 40-60 cm DBH class and comprised 2-7 % of the total volume produced. Based on this result, the proportion of harvestable trees in the 40-60 cm DBH class adopted for the CL and RIL units were 7 % and 2 %, respectively.

In extracting 9 to 13 trees of above 40 cm DBH, the overall damage inflicted on the residual forests averaged 60 % and 30 % in the CL and RIL units, respectively. The damage recorded in CL units is similar to figures reported for other sites in Sabah (e.g. Fox, 1969; Chai and Udarbe, 1977; Table 4.14) but considered to be high when compared to only 11 % in Gabon (White, 1994); 18 % in Nigeria (Ola-Adams, 1987); and 26 % and 43 % in Brazil (Uhl and Viera, 1989; Versissimo *et. al.*, 1992).

The considerably lower damage level in the RIL units compared to CL units was due to several factors. First, the removal of climbers before felling in RIL units had presumably reduced the overall proportion of trees with crown snapped-off compared with CL units by reducing the incidence of pull-downs of poles and saplings (e.g. Putz and Appanah, 1984). Lianes are known to use trees as a trellis to reach the forest canopy and in the process create cross-links among tree crowns. During tree felling, lianes-laden trees cause more damage to the residual forest than lianes-free trees of the same size (Fox 1968). It seems that pre-felling lianes cutting is the silviculturally most sensible control method compared to poison-girdling (Putz, 1993).

Second, the benefit of directional felling was most evident for trees in the 5-40 cm DBH range where the remaining stem density was higher in the RIL units compared with CL units. In RIL units, trees were marked for directional felling with due consideration to the presence of existing regeneration so that felling damage is kept to a minimum. Furthermore, trees were felled in a direction to facilitate skidding to minimize the bulldozer's movements thereby reducing incidental damages (Fox, 1969). The practice of directional felling did not reduce the incidence of snap-off in the RIL units: presumably, the trees that were harvested had large structures (in terms of crown and stem) that cause unavoidable canopy damage to the smaller trees.

Third, better planning of skid trails in RIL made an important contribution to reducing damage in RIL units. With skid trails being marked on the ground, the bulldozer operator had a better sense of direction and purpose, hence, avoiding unnecessary bulldozer movements. Marking skid trails also prevented the bulldozer operator from

Table 4.14 Logging damage caused to unlogged trees by conventional logging practices

Location	% overall tree damage	% tree broken or fallen	% trees with bark or crown damage	Source
Peninsula Malaysia	55	–	–	Burgess, 1971
Peninsula Malaysia	64-69	–	–	Canonizada, 1978
Peninsula Malaysia	8-21	–	–	Borhan *et. al.*, 1987
Sarawak	40	–	–	Marn and Jonkers, 1982
Sarawak	48-72	–	–	Liew and Ong, 1986
Sabah	68-75	–	–	Fox, 1968
Sabah	30-40	–	–	Phillips, 1986
Sabah	12-74	62	12	Nicholson, 1979
Sabah	60	50	10	This study, 1999

driving the machine to the stump, and in the process, causing higher incidence of stem (trunk) bark damage. With planning, there are fewer skid trails and log landings in RIL units which reduce the loss of trees in these areas.

The mechanical effects of logging on the forest are known to last for several years after logging (Wan Razali, 1989). At 8-12 months following logging, the mortality rate of trees above 1 cm DBH in the study area (1.5-2.5 %) is similar to the mean annual mortality of 2.53 % reported by Korsgaard (1992) in Sarawak, Malaysia (Table 4.15). In the Malaysian state of Trengganu, Tang and Razali (1981) reported a 4.16 % mortality in the first year after logging which increased to 9.53 % in the second year. A recent study conducted within the Sabah Foundation forest concession reported a mean annual mortality rate of 5 % in logged forest over 6 years of monitoring (Udarbe, 1995). It is evident that tree mortality rates in heterogeneous tropical forest can vary with places and conditions. A recent investigation of mortality rate evaluations in heterogeneous tropical forests concluded that mortality rates based on stem turnover rates also vary with census period (Sheil and May, 1996). For this study, mortality rates of 6 % and 5 % were considered for CL and RIL units for the purpose of determining the net harvestable yield in the second harvest.

Harvesting timber using RIL techniques resulted in a substantial portion of timber forgone. These forgone timbers are found on steep slopes, buffer zones, and areas where felling may be unsafe and caused environmental problems. The net timber volume forgone in RIL amounted to approximately 35 m^3 ha^{-1} after allowing for 50 % inaccessibility, cull and defects. This has serious economic implications unless alternative methods of timber harvesting are employed to 'salvage' these forgone timbers.

In summary, RIL techniques resulted in a better residual forest structure and biomass compared with forest logged with CL techniques. This difference is attributed mainly to the improved harvesting practices and logging restrictions in slopes above 35^o.

4.3.2. Growth and yield projection

4.3.2.1. Stand structure

The simulation results showed that the diameter distribution in the two treatment areas over a period of 60 years since the first harvest exhibited an inverse-J shape with the number of trees decreasing as size class increased (Figure 4.3). At the start of the simulation (year 1 after first harvest), 66 % of the total stem density (373 tree ha^{-1}) in the RIL units was in the 10-20 cm DBH class; 17 % in the 20-30 cm DBH, 8 % in the 30-40 cm DBH; 3 % in the 40-50 cm DBH and the remaining 6 % for trees greater than 50 cm

Table 4.15 Rate of tree growth and mortality in hill dipterocarp forest after logging

Location	Period (year)	D.M.A.I.* ($cm\ y^{-1}$)	Mortality rate (%)	Source
Selangor forest, P.Malaysia	10			Borhan *et al.*, 1987
- Dipterocarp		0.9		
- Light Heavy Hardwood		0.51		
- Medium/Heavy hardwood		0.38		
Trengganu, P. Malaysia	5	0.48-0.66	4.87	Tang and Wan Razali, 1981
Johore, P. Malaysia	5			
- Dipterocarp		0.85		Wan Razali, 1987
- Non-dipterocarp		0.67		
Batu Belah, Bukit Mersing, Niah and Sawai, Sarawak	15	0.23-0.41	2.53	Primack *et al.*, 1989
Segaluid-Lokan F.R., Sabah	11.2	1.05		Fox and Chai, 1982
Kuamut F.R., Sabah	6			
- Dipterocarp		0.47	5.0	Trevor, 1995
- Non-dipterocarp		0.31		
Ulu Segama F.R., Sabah	1		1.5-2.5	This study, 1995

* D.M.A.I = Diameter Mean Annual Increment

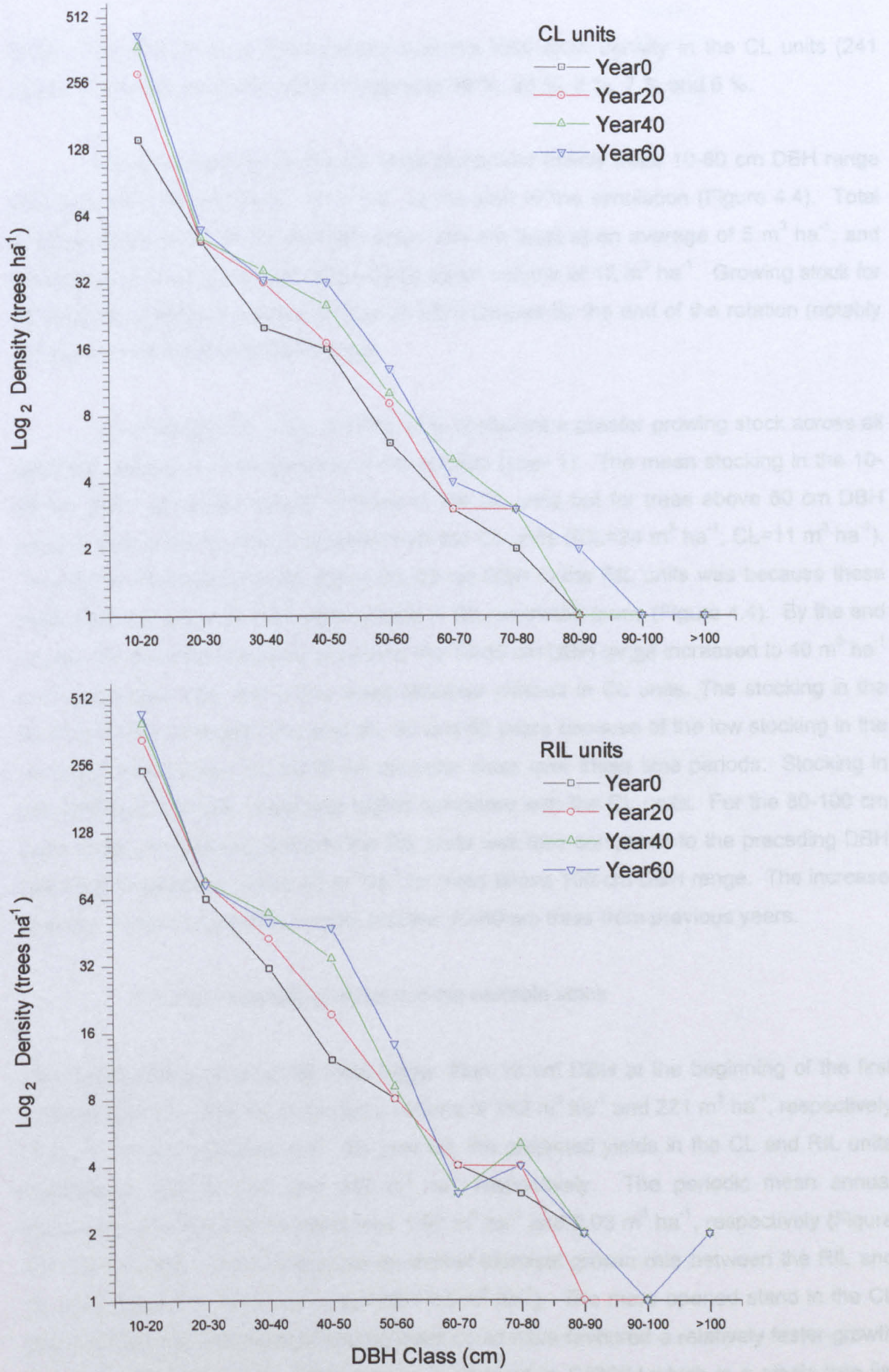


Figure 4.3 Simulated diameter distribution (logarithmic-transformed) in units logged with CL (top frame) and RIL techniques over time windows of 20-year intervals

DBH. The proportion of stem density over the total stem density in the CL units (241 trees ha^{-1}) for the respective DBH range was 59 %, 20 %, 8 %, 7 % and 6 %.

The growing stock in the CL units comprised mainly trees 10-60 cm DBH range with a mean total volume of 18 m^3 ha^{-1} at the start of the simulation (Figure 4.4). Total growing stock in the 80-90 cm DBH class was the least at an average of 5 m^3 ha^{-1}, and for trees over the 90 cm DBH range had a mean volume of 12 m^3 ha^{-1}. Growing stock for all diameter classes increased across all DBH classes by the end of the rotation (notably for those in the 30-60 cm DBH range).

In contrast to CL units, the RIL units contained a greater growing stock across all diameter classes at the beginning of the rotation (year 1). The mean stocking in the 10-60 cm DBH range was similar to those in the CL units but for trees above 60 cm DBH range it was twice as many compared with the CL units (RIL=24 m^3 ha^{-1}; CL=11 m^3 ha^{-1}). The higher stocking for trees above the 60 cm DBH in the RIL units was because these trees were left uncut as they were located in RIL-restricted areas (Figure 4.4). By the end of year 60, the mean stocking of trees in the 10-60 cm DBH range increased to 40 m^3 ha^{-1} and was higher than that in the same diameter classes in CL units. The stocking in the 60-70 cm DBH changed little over 20, 40 and 60 years because of the low stocking in the 40-50 cm that formed the 60-70 cm diameter class over these time periods. Stocking in the 70-80 cm diameter class was higher compared with the CL units. For the 80-100 cm DBH range, the growing stock in the RIL units was less compared to the preceding DBH class but increased to about 40 m^3 ha^{-1} for trees above 100 cm DBH range. The increase was due to carry-over of the higher stocked 70-80 cm trees from previous years.

4.3.2.2. Projected growing and harvestable stock

The total growing stock of all trees bigger than 10 cm DBH at the beginning of the first rotation in the CL and RIL units had a volume of 142 m^3 ha^{-1} and 221 m^3 ha^{-1}, respectively (Table 4.16 and Appendix 4.1). By year 60, the projected yields in the CL and RIL units increase to 260 m^3 ha^{-1} and 343 m^3 ha^{-1} respectively. The periodic mean annual increment (p.m.a.i) over 60 years was 1.97 m^3 ha^{-1} and 2.03 m^3 ha^{-1}, respectively (Figure 4.5; Table 4.16). The model gives an almost identical growth rate between the RIL and CL units (year 1 = 79 m^3 ha^{-1}, year 60 = 83 m^3 ha^{-1}). The more opened stand in the CL units, hence, less competition among trees could have favoured a relatively faster growth rate than in the RIL units. This feature is inherent in *DIPSIM* which is a single-tree list spatial model that uses information about the position and size of neighbouring trees to simulate the growth of individual trees in the plot. However, the number of trees in the CL units was fewer compared with RIL units.

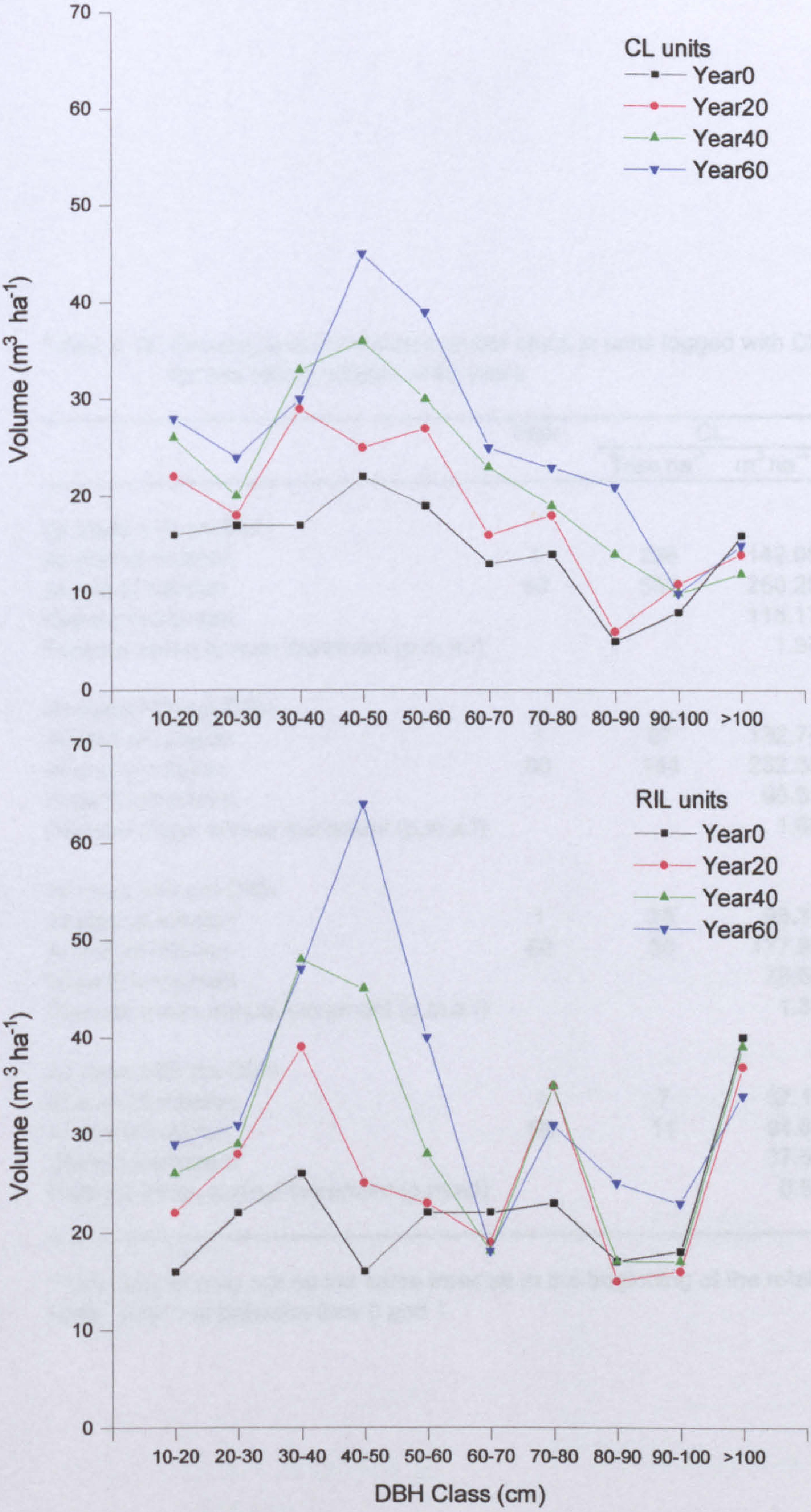


Figure 4.4 Simulated growing stock in CL (top frame) and RIL (bottom frame) units over four time periods 0, 20, 40 and 60 years after logging

Table 4.16 Growing and harvestable timber stock in units logged with CL and RIL techniques for one felling rotation of 60 years

	Year	CL		RIL	
		Tree ha^{-1}	m^3 ha^{-1}	Tree ha^{-1}	m^3 ha^{-1}
All trees >10 cm DBH					
At start of rotation	1	238	142.08	370	220.99
At end of rotation	60	567	260.25	624	342.66
Growth increment			118.17		121.67
Periodic mean annual increment (p.m.a.I)			1.97		2.03
All trees >20 cm DBH					
At start of rotation	1	97	132.74	127	204.97
At end of rotation	60	144	232.35	187	313.85
Growth increment			99.61		108.88
Periodic mean annual increment (p.m.a.I)			1.66		1.81
All trees >40 cm DBH					
At start of rotation	1	28	98.37	32	157.60
At end of rotation	60	56	177.95	73	235.76
Growth increment			79.58		78.16
Periodic mean annual increment (p.m.a.I)			1.33		1.30
All trees >60 cm DBH					
At start of rotation	1	7	57.15	13	119.20
At end of rotation	60	11	94.84	13*	130.96
Growth increment			37.69		11.76
Periodic mean annual increment (p.m.a.I)			0.63		0.20

* This may or may not be the same trees as at the beginning of the rotation
Note: year 1 is between time 0 and 1

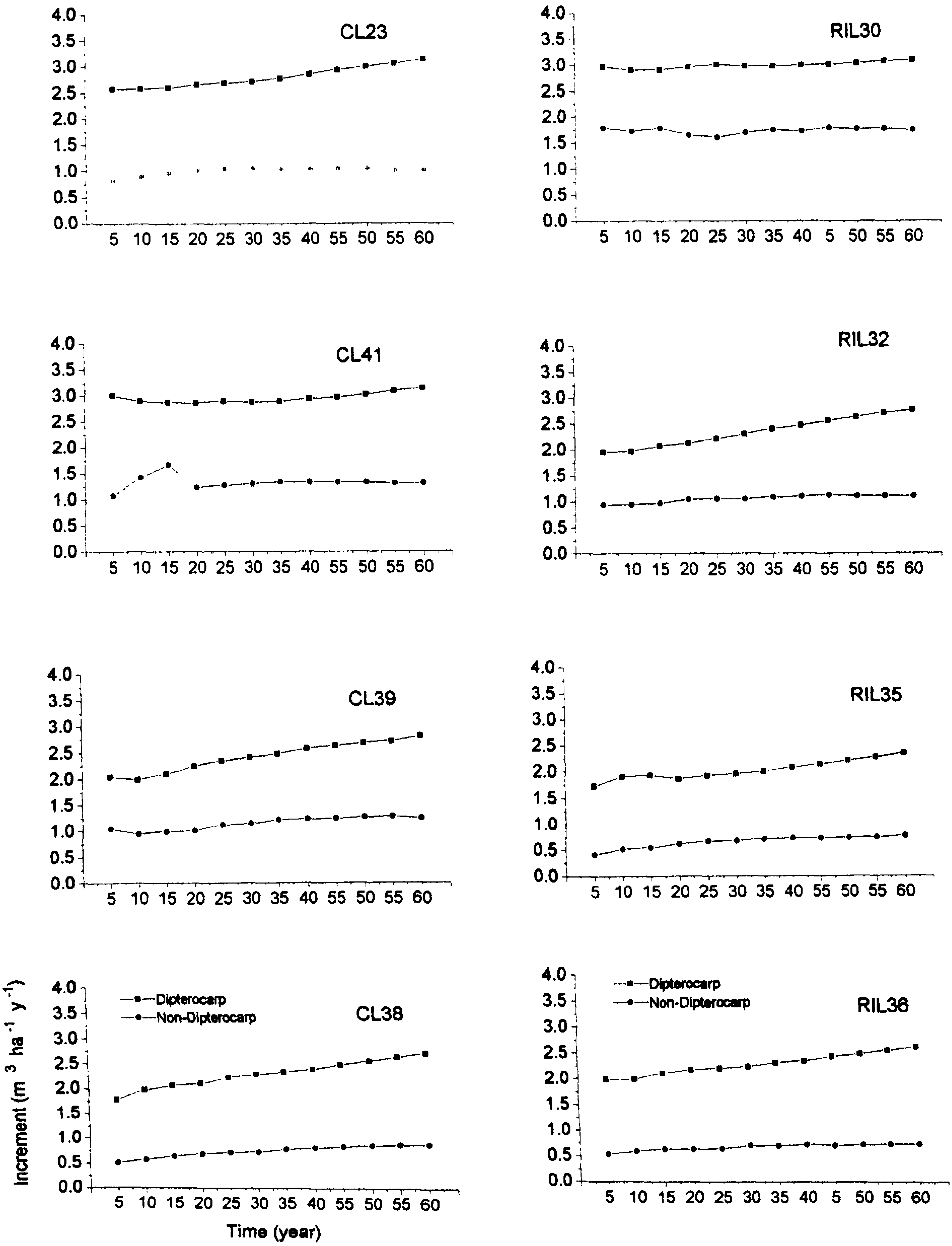


Figure 4.5 Periodic mean annual increment (m^3 ha^{-1} y^{-1}) in the four logging units logged by CL and four units by RIL techniques for the dipterocarp and non-dipterocarp species groups

Total growing stock for trees bigger than 40 cm DBH for all species in the CL and RIL logging units at the beginning of the first rotation was 98 m^3 ha^{-1} and 158 m^3 ha^{-1}, respectively rising to 178 m^3 ha^{-1} and 236 m^3 ha^{-1} respectively by the end of the rotation (Table 4.16). The new growth for this size class in the CL and RIL was 80 m^3 ha^{-1} and 78 m^3 ha^{-1} with p.m.a.i of 1.33 and 1.30 m^3 ha^{-1} yr^{-1} over 60 years.

Trees above 60 cm DBH produced a much lower p.m.a.i in CL and RIL units at 0.63 and 0.20 m^3 ha^{-1} yr^{-1}, respectively. In RIL units, there were as many trees recruited into the 60 cm DBH class as died resulting in a growth of only 12 m^3 ha^{-1}. The lower p.m.a.i. for trees greater than 60 cm DBH in the RIL units was presumably due to higher above- and below-ground competition because of the higher tree density and volume.

The net yield (excluding non-commercial timbers, mortality, wastage and cull) for trees that had reached harvestable size of over 40 cm DBH (taking only 5% of trees in the 40 cm DBH and all trees above 60 cm DBH) for CL and RIL units were 85 m^3 ha^{-1} and 111 m^3 ha^{-1}, respectively (Appendices 4.2 and 4.3).

4.3.2.3. Model output validation

There are a limited number of studies on growth modelling of logged tropical forests that extend to more than 40 years which make the comparison and validation of growth models difficult. Although there are models that have been developed for tropical forests outside Malaysia, they may not be applicable here because of different forest types, species, tree density and site quality. With this in view, the projected growths in the RIL and CL units modeled using *DIPSIM* were compared with the results of two growth modelling studies in Malaysia; by Bossel and Krieger (1994) as well as Ong and Kleiner (1995) for work carried out in Sabah.

The simulated growth in the logged forest of CL and RIL had tree density of greater than 10 cm DBH of 567 trees ha^{-1} and 624 trees ha^{-1}, respectively (Appendix 4.1). The corresponding stem volumes per ha were 260 m^3 ha^{-1} and 343 m^3 ha^{-1}, respectively. The simulated new growth in the logged CL and RIL units for trees above 10 cm DBH was 118 m^3 ha^{-1} and 122 m^3 ha^{-1}, respectively and the p.m.a.i. were 1.97 and 2.03 m^3 ha^{-1} yr^{-1}, respectively (Table 4.16). For trees greater than 60 cm DBH, the stem density in CL and RIL units were 11 and 13 trees ha^{-1}. The corresponding volumes for the two treatment areas were 95 and 131 m^3 ha^{-1}.

Bossel and Krieger (1994) using a physiological model (FORMIX2) and data from a less intensively logged 10 year old forest in Sabah (Deramakot forest reserve) projected total stem volume to be 345 m^3 ha^{-1} in 60 years (tree density and p.m.a.i. not given). For a more intensively logged forest over the same time frame, the projected volume of trees with diameter greater than 10 cm DBH was 245 m^3 ha^{-1}. The projected volume for RIL units was 343 m^3 ha^{-1}, which approximated the total stem volume in a less intensively logged forest of 345 m^3 ha^{-1} reported by Bossel and Krieger (1994). However, the difference in volume between the more intensively logged forest was much greater when compared with the projected volume in RIL and CL units. The difference in stocking between estimates produced by Bossel and Krieger (1994) and this study might have been due to the different degree of logging disturbance in the two areas. If only trees greater than 60 cm DBH were considered, the volume projected by Bossel and Krieger (1994) was 91 m^3 ha^{-1} against 95 m^3 ha^{-1} and 131 m^3 ha^{-1} in this study for CL and RIL units, respectively. The simulated stock between the two sets of figures for the conventionally logged forest was comparable.

Using *DIPSIM*, Ong and Kleiner (1995) presented growth simulation results for a tractor-logged Segaliud-Lokan forest reserve in eastern Sabah (Sandakan). The results of the 40-year simulation showed growing stock for commercial trees greater than 10 cm DBH was 223 m^3 ha^{-1} with a periodic annual increment of 2.6 m^3 ha^{-1} yr^{-1} (tree density not reported). For trees greater than 60 cm DBH, the density was 8 trees ha^{-1} (growing stock and p.m.a.i. not given). Growth in the Segaliud-Lokan forest reserve appeared to level off between year 35-40. The simulated growing stock for trees greater than 10 cm DBH in the Segaliud-Lokan was lower than the growing stock in the RIL and CL units but periodic mean increment was higher for Segaliud-Lokan. The difference in growing stock between studies could be attributed to the degree of logging intensity where the Segaliud-Lokan had been logged with greater intensity and frequency (Ong and Kleiner, 1995). The more opened stand in Segaliud-Lokan resulted in faster growth rates (indicated by the p.m.a.i.) due to lesser competition. In *DIPSIM* , competition for individual tree is modelled with reference to the total surrounding stand basal area of all trees greater than 10 cm DBH in a plot (called the basal area) and the basal area of all surrounding trees whose diameter is greater than the individual tree to be modelled (called the overtopping basal area). Such model may be biased for more opened stands (higher disturbance) resulting in higher growth rates compared to a less opened stand (e.g. RIL-logged). The density for trees greater than 60 cm DBH in Segaliud-Lokan was within the range of 7-11 trees ha^{-1} found in the study areas.

In summary, the simulated growing stock and p.m.a.i. in the CL and RIL units are within the estimates reported by other studies (e.g. Bossel and Krieger, 1994; Ong and Kleiner, 1995). The p.m.a.i. in the two study areas (RIL=1.97 m^3 ha^{-1} yr^{-1}; CL=2.03 m^3 ha^{-1} yr^{-1}) for trees greater than 10 cm DBH over 60 years was close to the top of the range of 0.5-2.0 m^3 ha^{-1} yr^{-1} reported in Sabah (e.g. Appanah *et al.*, 1993; Tang, 1976; Trevor, 1995). These p.m.a.i. may be conservative as one study in Sarawak for a logged-over mixed peat swamp forest had projected p.m.a.i. for trees over 10 cm DBH to be 2.9 m^3 ha^{-1} yr^{-1} after 27 years since logging (Chai and Sia, 1994). If left undisturbed for another 10 years, the p.m.a.i. in these forest was 2.7 m^{-3} ha^{-1} yr^{-1}; only a small decline.

4.3.3. Timber revenue

4.3.3.1. Timber grades

A total of 18,744 logs containing 116,894 m^3 from coupes YL2/93 and YL4/93 was analyzed to determine their grade distribution by individual species/species group (Appendix 4.4). Taking all species, 8 % of the total timber volume produced from the two coupes was of FAQ grade; 10 % in the SSQ grade; 49 % in the SQ grade; 16 % in the MQ grade and the remaining 18 % were SM and MQL grades. The high proportion of SQ logs was because some timber species could only be graded to SQ grade under the Sabah Log Grading Rules (1984). These species were the kapur, keruing and the selangan batu. The log grade distribution in these two coupes was consistent with other coupes within the Sabah Foundation concession area and the composition of SQ and up was 67 %.

4.3.3.2. Log prices

The 1993 Sabah Foundation's F.O.B. log price ex-log pond ranged from RM147 m^{-3} to RM347 m^{-3} (average value was RM247 m^{-3}) depending on the timber species (Appendix 4.1). Between species, the merbau and the agathis fetched the highest price valued above RM300 m^{-3}. However, these species contributed only a small proportion of the timber production because they only grew on specific sites preferring sandy sites. The seraya is the next most valuable timber with prices ranging from RM165-286 m^{-3} depending on the timber grade. The kapur, keruing and the selangan batu are priced between RM160-178 m^{-3}. Other less valuable timber species fetched prices in the region of RM164 m^{-3}. The log price difference between grades was significant and between the FAQ and SSQ was RM10 m^{-3}; SSQ and SQ was RM21-37 m^{-3}; and SQ and MQ was RM7-20 m^{-3}.

The Sabah Foundation's F.O.B. log prices were within the range reported by the Malaysian Timber Council (1995). In 1992, 1993, and 1994: the average F.O.B. log price for logs produced from Malaysia was RM215, RM314 and RM302 m^{-3}, respectively (Malaysian Timber Council, 1995). Most species of Asian logs were trading between RM250-RM370 m^{-3} between 1992-1994 (ITTO, 1996). A timber sector review undertaken by a stock investment analysis company, the *Deutsche Morgan Grenfell*, in 1996 for several public listed forestry enterprises in Malaysia reported log prices ranging from RM352-RM433 m^{-3} for the period 1995-1997.

4.3.3.3. Log price outlook

According to the study carried out by ITTO (1993), the supply of saw and veneer quality logs from tropical forests in the major producer countries (Indonesia, Malaysia, Papua New Guinea and Philippines) will not be able to meet increasing demand in the main consuming countries (Japan, South Korea, China, Taiwan, Hong Kong, Thailand and Singapore) for the period 1993-2010. Supply was projected to decline by 30 % from 85 million m^3 in 1988 to 59 million m^3 by the end of 2010 (ITTO, 1993). Conversely, the demand for tropical timber in consuming countries was expected to exceed supply with a deficit of 55 million m^3 by 2010. These log supply and demand scenarios were generated from the three computer models namely the *log, gap* and *market* models that have been discussed in section 4.2.2.3.2.

As a result of the increasing scarcity of logs after 1993, the ITTO study forecasts that real product and log prices would rise at a mean rate of 2.5 % (range of 1 to 4 %) per year for sawnwood and plywood (range of 1 to 3 %) per year in the consuming countries. In the producing regions, prices were predicted to increase much faster because of rising domestic demand: at a rate of 9 % (range of 2.7 to 4.4 %) per year for sawnwood and 4 % (range of 3.3 to 4.2 %) per year for plywood. The predicted increase in prices assumed a continuous scarcity of logs during the forecast period and a 5 % constraint imposed on the volume of substitution. The substitutions are in various forms including oriented strand board (OSB) for plywood, medium density fibreboard (MDF) and particle board, laminated veneer lumber (LVL) for container flooring or building, wood fibre or cement bonded fibreboard as well as non-wood products such as plastics, aluminum, steel alloy and the like.

Based on the ITTO's study, this study assumes a 2 % real price increase per annum for the forecast period. This is a conservative estimate which recognizes that price increase for products doesn't translate into that for stumpage. The mean projected price increase of 2 % per year for the consumer's countries is also consistent with the rate used by the Food and Agricultural Organisation (1988 and1990).

4.3.3.4. Log revenue

The weighted log revenue for the first harvest (at year 1) from the CL and RIL units was RM200 m^{-3} and RM 196 m^{-3}, respectively (Appendix 4.5). For the second harvest (at year 60), the estimated revenue was RM650.46 m^{-3} and RM662.32 m^{-3}, assuming a

2 % real price increase per annum (Appendix 4.2 and 4.3). The difference in log revenue between the CL and RIL units was attributed to difference in log size.

4.3.4. Costing

4.3.4.1. Felling time and motion study

The mean tree DBH in CL units was bigger than that in RIL units by 7 cm but the difference was not significant ($mean_{RIL}$=85 cm $\pm$2.94 SE; $mean_{CL}$=93 cm $\pm$3.26 SE; t=1.658, P=0.07; Table 4.17). Mean tree length was, however, significantly different between treatment areas ($mean_{RIL}$=22 m $\pm$0.59 SE, $mean_{CL}$=19 m $\pm$1.28 SE; t=2.292, P=0.024) and might have an effect on the time taken to fell a tree. There was insufficient trees in the RIL and CL units to compare felling times for trees of the same size. The total time taken to fell a tree differed significantly between RIL and CL techniques (t=4.354, P<0.001). RIL took 32.04 min $\pm$2.70 SE and CL took 18.56 min 1.52 SE; Table 4.17).

The primary reason for the difference in total felling time between RIL and CL was attributed to differences in work organization and the manner of executing the individual work elements. In RIL, fellers cut down only 2 to 3 trees at a time in one area to minimize damage inflicted by falling trees on trees that were previously felled but not yet removed from the stump. It was also to ease skidding jams where fallen trees have stacked on each other amidst logging debris. Bucking was done immediately after felling to facilitate skidding. In CL practices, fellers fell trees uninterrupted from 7.00 am to 11.30 am, and with no apparent regard to the facilitation of skidding. In most cases, bucking of trees was left unfinished and had to be postponed until skidding activity commenced because of the congestion created by too many trees in one spot.

The total time taken to execute the productive felling work elements per tree in RIL took significantly longer than in CL ($mean_{RIL}$=21.29 min $\pm$2.95 SE; $mean_{CL}$=13.33 min $\pm$1.51 SE; t=5.385, P<0.001; Figure 4.6). The time taken to *search* and prepare trees for felling in RIL and CL did not differ significantly even though trees in the RIL unit had been prior marked for felling and cleared of woody vines. RIL fellers took significantly longer to *direct* the fall of a tree because they have to fell a tree within $\pm 10^{o}$ of the marked felling direction; fell the tree in a direction to facilitate skidding; minimize breakage of the harvested tree and damage to the regeneration; avoid felling into streams and riparian reserves. *Felling* a tree also took significantly longer in RIL because RIL fellers had to make precise backcut and felling cut to achieve the desired falling direction. RIL also took longer to *buck* a tree even though there were fewer trees in the stack compared with

Table 4.17 Comparison of felling times between CL and RIL techniques

Felling	RIL			CL			t values	P values	t-test*
	Mean	SE	% of total time	Mean	SE	% of total time			
Total number of trees	59			59					-
Basal area (m^2) per tree	0.60	0.04		0.72	0.06				
Volume (m^3) per tree	13.0	1.06		13.4	1.41		1.659	0.944	**n.s.**
DBH (cm)	85.0	2.94		93.0	3.26		1.658	0.073	**n.s.**
Length (m)	22.0	0.59		19.0	1.28		-2.298	0.0245	*
Productive time (min)									
Search for tree	1.52	0.40	4.74	1.44	0.20	7.76	-0.191	0.849	**n.s.**
Clear debris	1.01	0.20	3.15	1.12	0.13	6.03	0.423	0.673	**n.s.**
Direct fall	1.79	0.20	5.59	0.40	0.13	2.16	-5.829	<0.001	***
Fell tree	6.67	0.56	20.82	4.72	0.44	25.43	-2.666	0.009	**
Buck tree	7.91	1.08	24.69	5.56	0.56	29.96	-1.945	0.055	**n.s.**
Others	2.39	0.51	7.46	0.09	0.05	0.48	-4.514	<0.001	***
Sub-total	**21.29**	**2.95**	66.45	**13.33**	**1.51**	71.82	-5.385	<0.001	***
Non-productive time (min)									
Wait	1.39	0.58	4.34	0.02	0.01	0.11	-2.365	0.021	*
Mechanical	4.11	0.99	12.83	4.20	0.89	22.63	-0.067	0.947	**n.s.**
Idle	2.26	0.80	7.05	0.19	0.11	1.02	-2.555	0.013	*
Personal	2.99	0.95	9.33	0.82	0.38	4.42	-2.132	0.0363	*
Sub-total	**10.75**	**1.76**	33.55	**5.23**	**0.98**	28.18	-2.744	0.0073	**
Total	**32.04**	**2.70**	**100.00**	**18.56**	**1.52**	**100.00**	-4.354	<0.001	***

*** P values < 0.001; ** 0.001<P<0.01; * 0.01<P<0.05

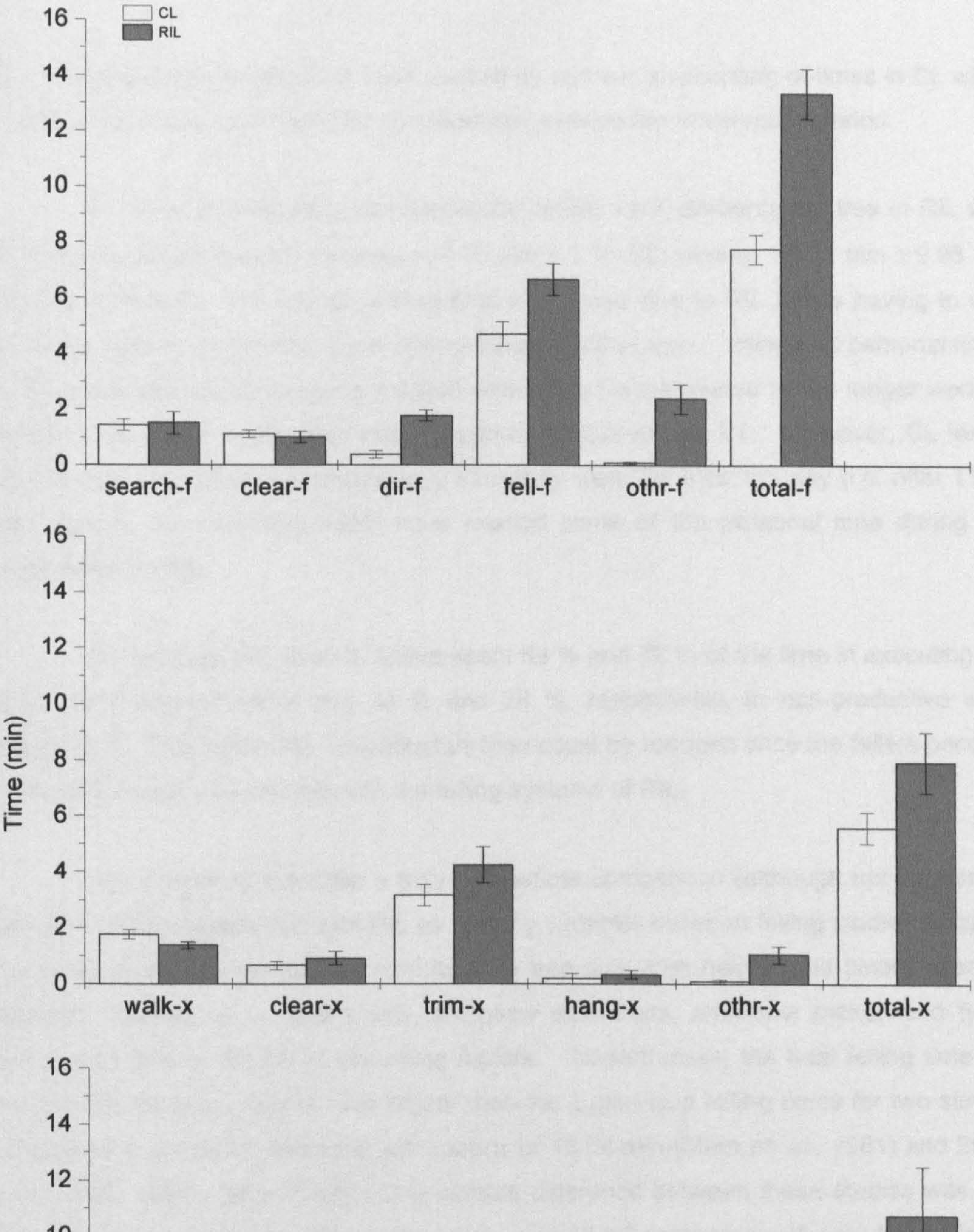


Figure 4.6 Felling time for CL and RIL techniques. The top frame shows the time taken to fell tree, the middle frame shows the time taken to buck fallen trees, and the lower frame shows non-productive time

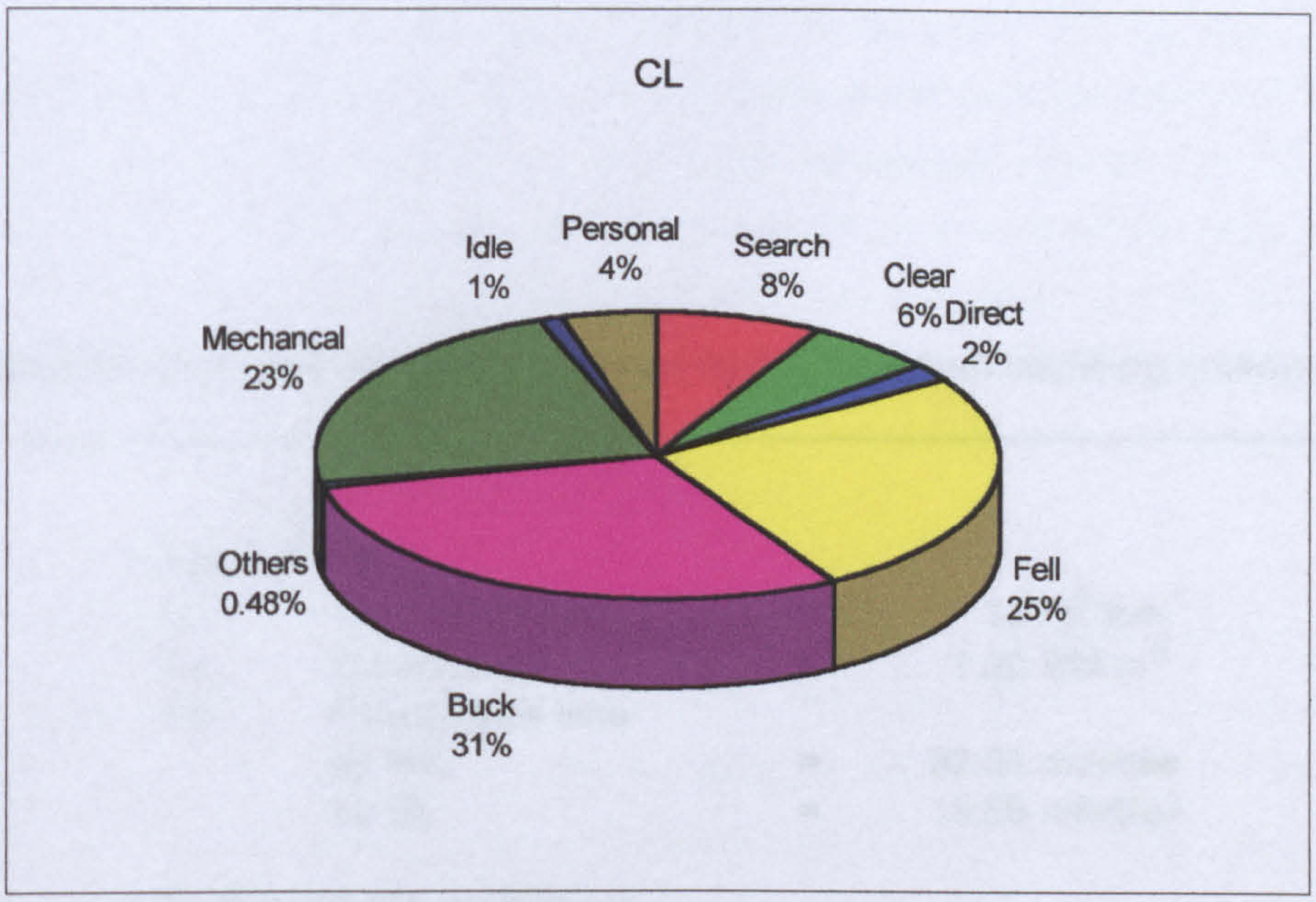
CL. This peculiarity might have been caused by some mis-recording of times in CL when bucking operations were deferred and executed outside the observation period.

The total time spent in non-productive felling work elements per tree in RIL was significantly longer than CL ($mean_{RIL}$=10.75 min ± 1.76 SE; $mean_{CL}$ =5.23 min ± 0.98 SE; t=2.744, P=0.007). The longer *waiting* time in RIL was due to RIL fellers having to wait for fallen trees to be skidded away before felling another tree. *Idling* and *personal* times in RIL were also much longer compared with CL but were related to the longer working hours in RIL which made them more apparent compared with CL. Moreover, CL fellers usually took their rests and breaks only after they were done for the day (i.e. after 11.30 am), hence, the recorders might have missed some of the personal time during the observation period.

On average, RIL and CL fellers spent 66 % and 72 % of the time in executing the productive work elements and 34 % and 28 %, respectively, in non-productive work (Figure 4.7). The higher RIL unproductive time could be reduced once the fellers become more conversant and efficient with the felling systems of RIL.

It is difficult to establish a truly compatible comparison (although not impossible through multiple regression with RIL as dummy variable) between felling studies because the times would presumably be correlated to tree size, tree height, and timber species. Besides, differences in feller's skill, chainsaw sharpness, chainsaw makes and types would also add to the list of disturbing factors. Nevertheless, the total felling time per tree for RIL ($mean_{RIL}$=32.04) was higher than the supervised felling times for two studies conducted in Sarawak, Malaysia with means of 15.68 min (Marn *et. al.*, 1981) and 20.06 min (Chua, 1986), respectively. One notable difference between these studies was that the mean volume per tree felled in this study was 13 m^3 compared with only 5-7 m^3 in the studies conducted Marn *et. al.*, (1981) and Chua (1986). Another factor was the different work methods among studies where felling of trees in this study was restricted to 2-3 trees at one time while the two studies maintained a continuous felling of trees. However, the total felling time for CL ($mean_{CL}$18.56 min) in this study was comparable with the results of unsupervised felling times in the two studies (means of 10.41 min and 18.38 min, respectively).

Based on the findings of this study, a feller who is paid piece rate using RIL techniques faced an income loss of 42 % compared to CL (Table 4.18). This calculation assumed a felling time of 32.04 min and 18.56 min for RIL and CL respectively per 13 m^3 tree at a felling contract rate of RM1.30 m^{-3}. Therefore, to promote RIL acceptance, RIL fellers need to be compensated for the reduced income. A direct compensation of the income reduction would increase the present felling rate of RM1.30 m^{-3} to RM2.20 m^{-3}



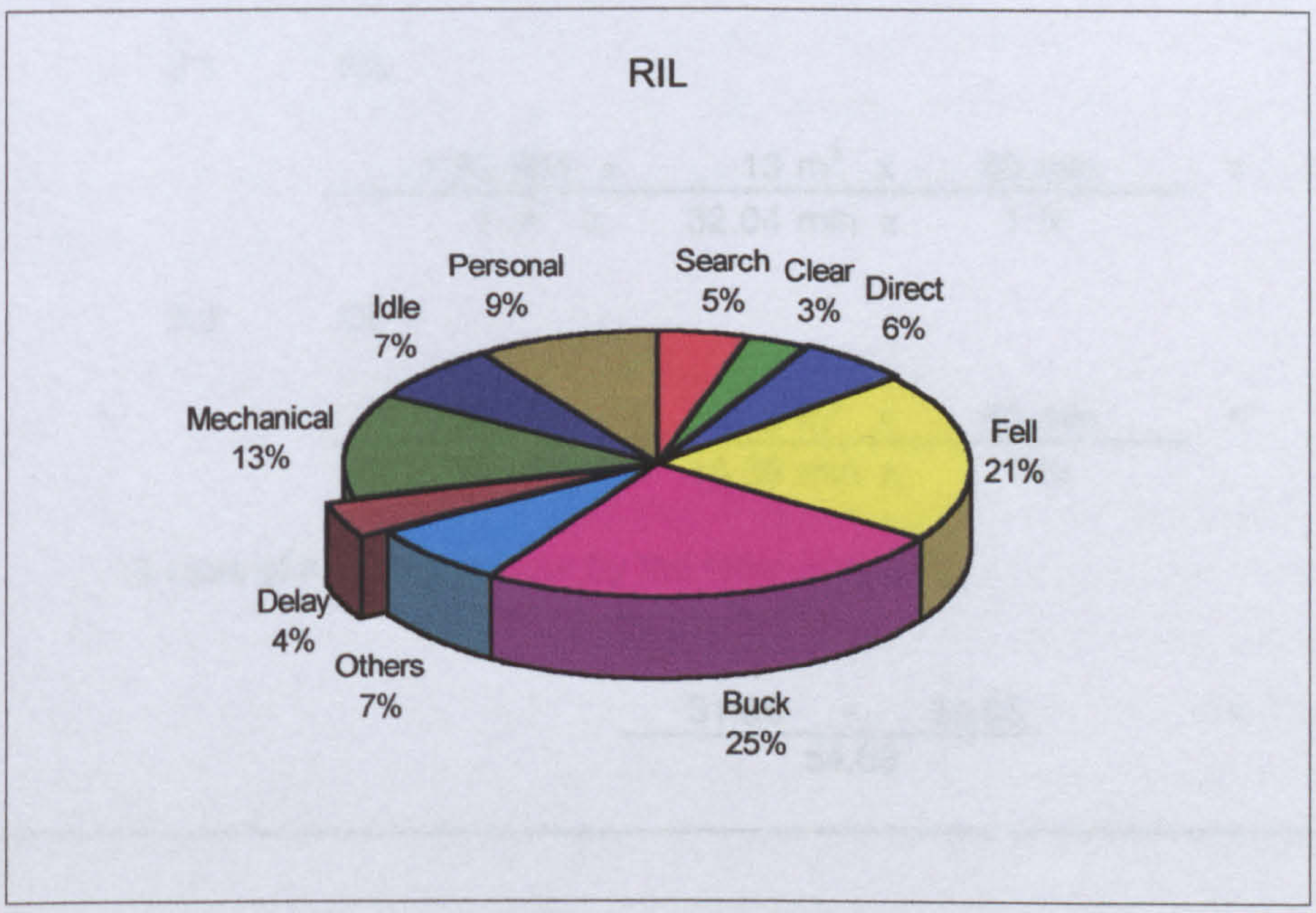


Figure 4.7 Percentage of felling time for CL and RIL techniques. In RIL and CL, 66 % and 72 % of the time was spent in productive work elements and 34 % and 28 %, respectively, in non-productive work elements.

Table 4.18 Estimates of the hourly income for the feller from the felling operation

1 Assumptions

1.1	Volume per tree	=	13 m^3 $tree^{-1}$
1.2	Contract rate	=	1.30 RM m^{-3}
1.3	Felling cycle time		
	a) RIL	=	32.04 min/tree
	b) CL	=	18.56 min/tree

2 Cost calculation in RM/hour

2.1 RIL

$$\frac{1.30\ \text{RM} \times 13\ \text{m}^3 \times 60\ \text{min}}{1\ \text{m}^3 \times 32.04\ \text{min} \times 1\ \text{hr}} = 31.65\ \text{RM hr}^{-1}$$

2.2 CL

$$\frac{1.30\ \text{RM} \times 13\ \text{m}^3 \times 60\ \text{min}}{1\ \text{m}^3 \times 18.56\ \text{min} \times 1\ \text{hr}} = 54.63\ \text{RM hr}^{-1}$$

3 Loss of income per hour by the feller due to RIL

$$\frac{31.65 - 54.63}{54.63} = 42.07\ \%$$

(or by 1.7 times). The new rate would still be within the range reported in Sarawak by Marn *et. al.* (1981) of between RM2.29 m^{-3} to RM2.31 m^{-3}. A second option would be to pay RIL fellers a basic daily wage in addition to the piece rate as compensation for waiting time between work elements. A third option would be to pay the RIL fellers a cash advance based on the estimated value of the harvestable (greater than 60 cm DBH) standing stock if their monthly earnings fall short of a subsistence level during wet weather shut-downs. The most acceptable option to contractors and fellers would be to revise the felling rate upward to be commensurate with the additional work requirement.

4.3.4.2. Skidding time and motion study

The average log diameters in the RIL and CL areas were identical ($mean_{RIL}$ =79.0 cm ± 2.79 SE; $mean_{CL}$=79.0 ± 2.49 SE; t=0.135, P>0.892). Mean log length in the RIL logging unit was also not significantly different from that in the CL logging unit ($mean_{RIL}$=16.0 m ± 0.78 SE; $mean_{CL}$=17.0 m ± 0.78 SE; t=0.804, P=0.42;Table 4.19).

Total time required to extract a log using RIL techniques was significantly longer than in CL ($mean_{RIL}$=39.03 min ± 2.95 SE; $mean_{CL}$=23.57 min ± 2.39 SE; t=4.07, P<0.001). The main reason for the time difference was the different ways of skidding logs between techniques.

RIL skidding crews spent significantly more time in *pulling* winch cables to fallen trees, *hooking/unhooking* winch cables, *winching* and *stacking* logs (Figure 4.8). *Pulling* and *hooking* the winch cable to the log took longer in RIL reflecting the greater use of the winch cable. This was preferred in RIL rather than to let the operator drive the bulldozer up to the stump to hook up the log resulting in more open and longer skid trails, and causing higher incidental damage to the residual trees and soil. The greater use of the winch was achieved by confining the bulldozer to a marked position some distance away from the stumps. In RIL, the time taken to *winch* logs was significantly higher than in CL ($mean_{RIL}$=11.06min ± 0.87 SE; $mean_{CL}$=3.49 min ± 0.59 SE; t=7.112, P<0.001) because the direction of skidding was made uphill in order to disperse skid trail runoff. The time taken to *unhook* the winch cable and *stack* logs in RIL (0.65 min ± 0.06 SE) was also significantly higher than in CL (0.38 min ± 0.04 SE). The higher RIL time was because RIL bulldozer operators had to use roadsides as log landings that were narrower, which made log handling and manoeuvering the bulldozer difficult and more time consuming in performing log piling. In CL practice, logs are piled in spacious landings that have been bulldozed and cleared of any vegetation. Time spent for bulldozer in *empty travel* and *bladding* or levelling ruts left in skid trails after skidding for RIL (3.35 min ± 0.19 SE) was not significantly different (t=0.868, P=0.38) from CL (4.08 min ± 0.58 SE).

Table 4.19 Comparison of skidding times between CL and RIL techniques

Skidding	RIL			CL			t values	P values	t-test*
	Mean	SE	% of total time	Mean	SE	% of total time			
Total number of trees	55			58					
Basal area (m^2) per tree	0.523	0.04		0.520	0.03		-0.934	0.354	**n.s.**
Volume (m^3) per tree	7.5	0.40		8.5	0.63		-0.796	0.430	**n.s.**
Mean DBH (cm)	79.0	2.79		79.0	2.49		-0.135	0.892	**n.s.**
Mean length (m)	16.0	0.78		17.0	0.68		0.804	0.423	**n.s.**
Productive time (min)									
Search log	0.06	0.06	0.15	0.09	0.04	0.38	0.351	0.727	**n.s.**
Open skid trail	3.05	1.19	7.81	2.04	0.66	8.66	-0.737	0.463	**n.s.**
Clear debris	0.16	0.08	0.41	1.03	0.20	4.37	3.998	<0.001	***
Pull winch rope	1.56	0.20	4.00	0.69	0.09	2.93	-3.926	<0.001	***
Hook winch rope	1.94	0.17	4.97	0.90	0.19	3.82	-4.046	<0.001	***
Skid log	2.29	0.23	5.87	4.79	0.54	20.32	4.358	<0.001	***
Winch log	11.06	0.87	28.34	3.49	0.59	14.81	-7.112	<0.001	***
Anchor tractor	0.04	0.02	0.10	0.09	0.05	0.38	0.965	0.338	**n.s.**
Fight hang-up	0.95	0.49	2.43	0.67	0.24	2.84	-0.513	0.609	**n.s.**
Unhook winch rope	0.65	0.06	1.67	0.38	0.04	1.61	-3.472	<0.001	***
Stack log	1.84	0.11	4.71	1.38	0.16	5.85	-2.195	0.030	*
Empty travel	3.55	0.19	9.10	4.08	0.58	17.31	0.868	0.388	**n.s.**
Blade skid trail	0.76	0.34	1.95	0.55	0.24	2.33	-0.505	0.614	**n.s.**
Sub-total	**27.91**	**1.63**	71.51	**20.18**	**1.85**	85.62	-3.127	0.002	***
n-productive time (min)									
Mechanical	2.54	1.12	6.51	0.99	0.64	4.20	-1.199	0.234	**n.s.**
Winch snap	0.12	0.09	0.31	0.41	0.41	1.74	0.693	0.491	**n.s.**
Idle/Wait	2.44	0.78	6.25	1.10	0.38	4.67	-1.545	0.126	**n.s.**
Personal	6.02	1.35	15.42	0.89	0.39	3.78	-3.648	0.001	***
Sub-total	**11.12**	**2.16**	28.49	**3.39**	**1.22**	14.38	-3.125	0.002	**
Total	**39.03**	**2.95**	**100.00**	**23.57**	**2.39**	**100.00**	-4.072	<0.001	***

*** P values < 0.001; ** 0.001<P<0.01; * 0.01<P<0.05

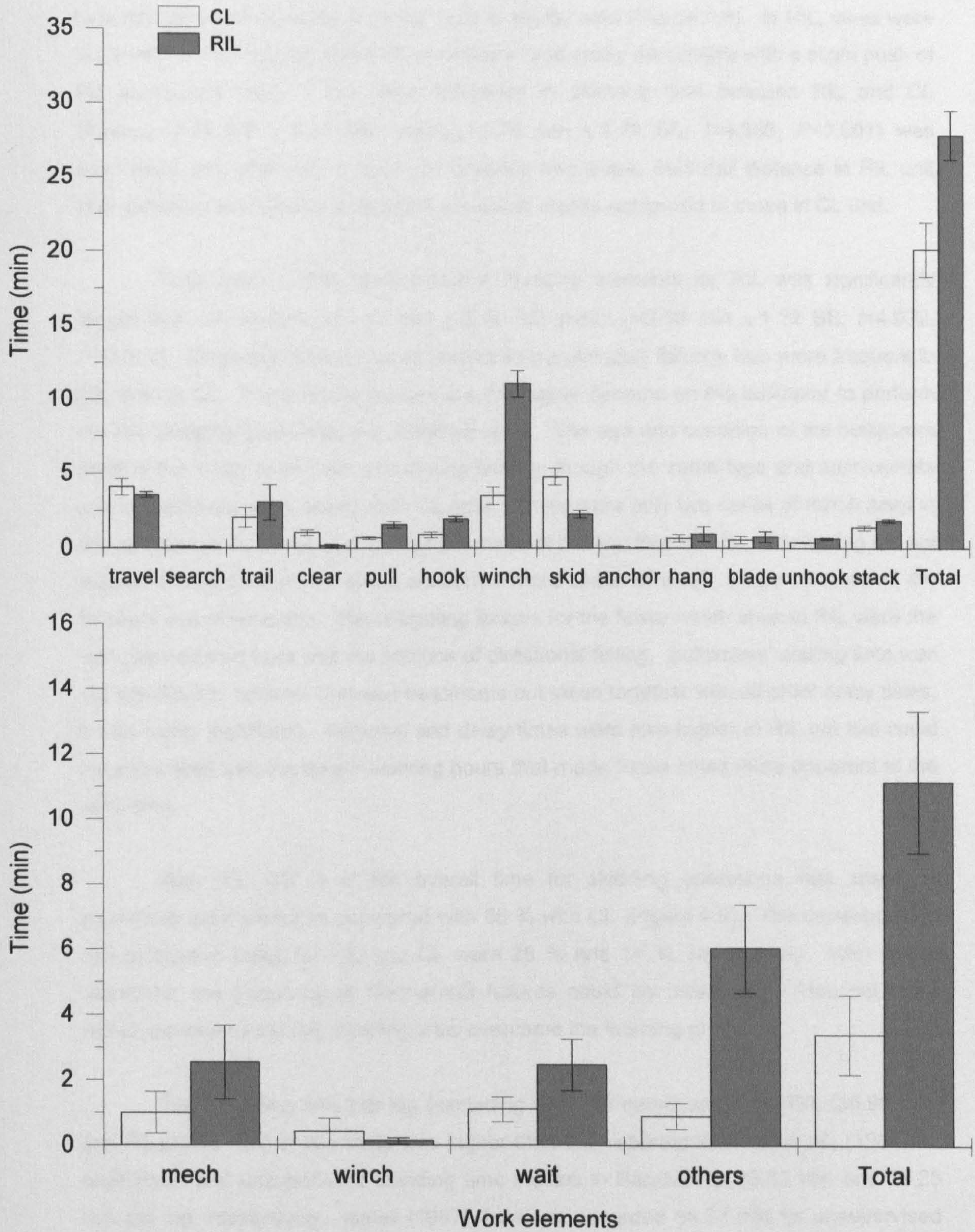


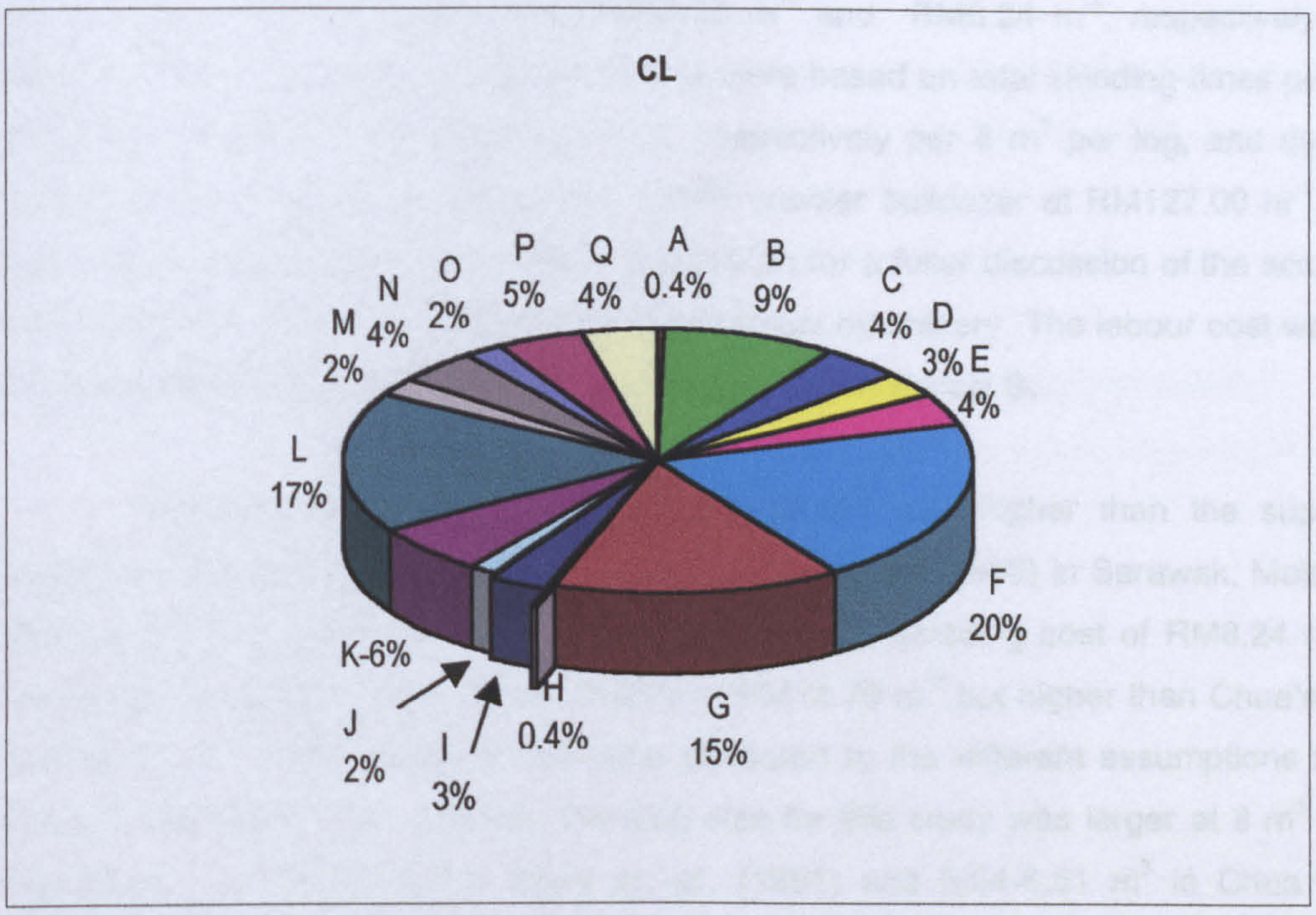
Figure 4.8 Skidding time for CL and RIL techniques. The top frame indicates productive times and the bottom frame non-productive times

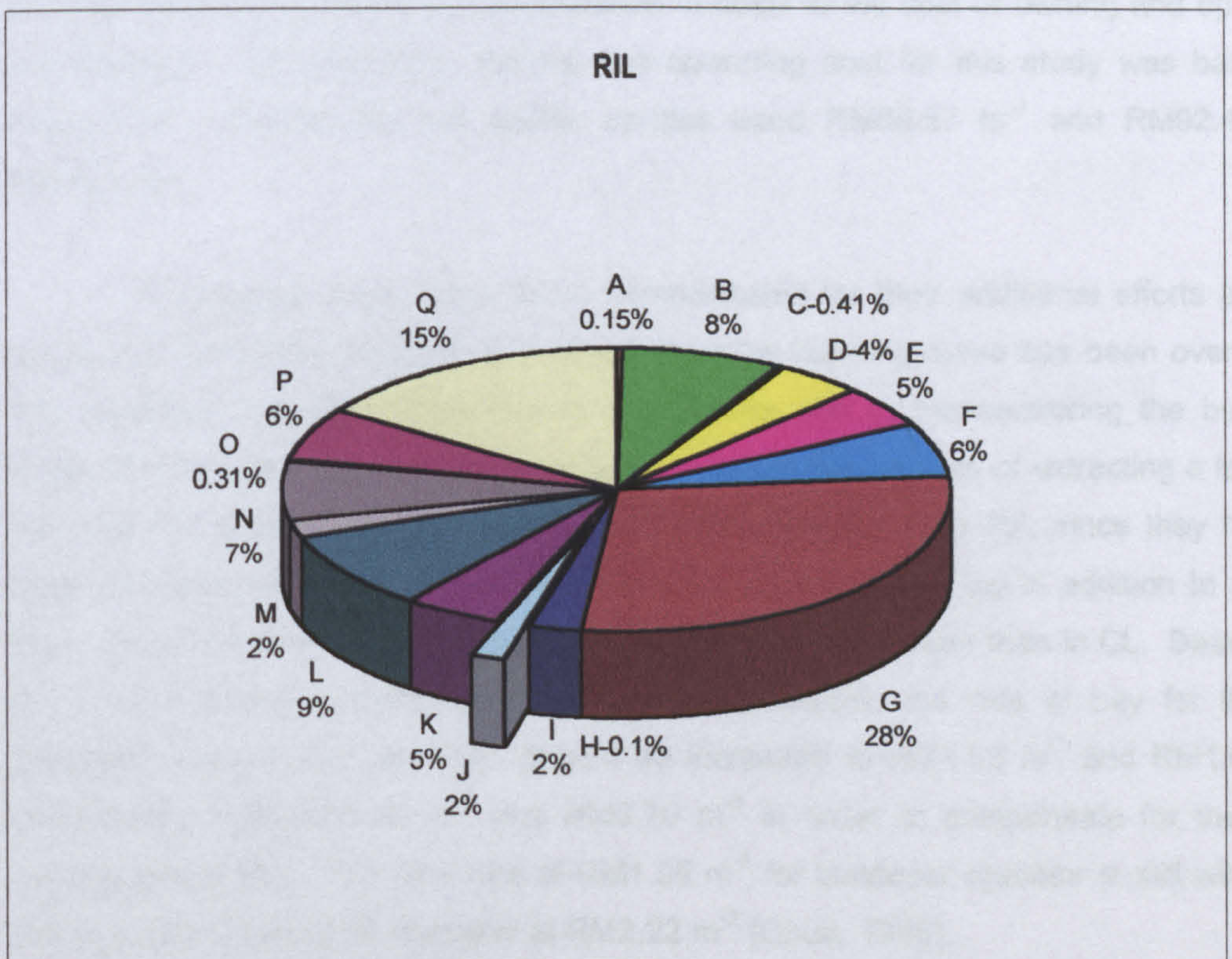
RIL skidding crews, however, spent significantly less time *clearing debris* attaching to logs, *skidding* and *travelling* from log deck to stump area (Figure 4.8). In RIL, vines were cut a year before logging therefore vine-debris was easily detachable with a slight push of the bulldozer's blade. The large difference in *skidding* time between RIL and CL ($mean_{RIL}$=2.29 min $\pm$0.23 SE; $mean_{CL}$=4.79 min $\pm$4.79 SE; t=4.358, P<0.001) was associated with difference in skid trail distance and slope. Skid trail distance in RIL unit was generally shorter and confined to shallower slopes compared to those in CL unit.

Time spent in the non-productive skidding elements for RIL was significantly longer than CL ($mean_{RIL}$=11.12 min $\pm$2.16 SE; $mean_{CL}$=3.39 min $\pm$1.22 SE; t=4.072, P<0.001). Stoppage of work due to *mechanical* (bulldozer) failures was more frequent in RIL than in CL. The possible causes are the higher demand on the bulldozer to perform the RIL skidding guidelines, e.g. skidding uphill. The age and condition of the bulldozers used in this study were also contributing factors, though the same type and approximate age of machines were deployed in CL units. There were only two cases of *winch snap* in RIL and one in CL out of all observations made of the two treatments. This finding did not support the claim that RIL would encounter more cases of winch snaps because of the frequent use of winching. The mitigating factors for the fewer winch snap in RIL were the well-planned skid trails and the practice of directional felling. Bulldozers' *waiting* time was not significantly different between treatments but taken together with all *other* delay times, it was highly significant. *Personal* and *delay* times were also higher in RIL but this could be associated with the longer working hours that made these times more apparent to the recorders.

With RIL, 72 % of the overall time for skidding operations was spent on productive work elements compared with 86 % with CL (Figure 4.9). The corresponding non-productive times for RIL and CL were 28 % and 14 %, respectively. With newer machines, the frequency of mechanical failures could be minimized. Personal times would improve as the RIL skidding crew overcome the learning phase.

Total skidding time per log (excluding skid trail construction) for RIL (35.98 min) and CL (21.53 min) in this study was higher than that reported in Marn *et. al.,* (1981) for supervised and unsupervised skidding time studies in Sarawak at 23.63 min and 19.25 min per log, respectively. Ismail (1987), however, recorded 36.37 min for unsupervised skidding for his study in Peninsula Malaysia. Chua (1986) recorded supervised and unsupervised skidding times at 25.88 min and 44.12 min, respectively, for his study in Sarawak, Malaysia. The inconsistency in times between studies could be due to different setting for the experiments; e.g. terrain, tree size, skidding distance etc. Also, payment system would affect the performance of the skidding crews between supervised and unsupervised skidding (Price, 1989).





Legend: A=Search, B=Open skid trail, C=Clear, D=Pull, E=Hook, E=Skid, G=Winch, H=Anchor, I=Hang-up, J=Unhook, K=Stack, L=Empty travel, M=Blade, N=Mechanical, O=-Winch repair, P=Waiting, Q=Personal time

Figure 4.9 Percentage of skidding time for CL and RIL techniques. In RIL and CL, 72 % and 86 % of the time was spent in productive work elements and 28 % and 14 %, respectively, in non-productive work elements

The estimated skidding costs for RIL and CL techniques based on the result of the time and motion studies were RM12.33 m^{-3} and RM8.24 m^{-3}, respectively: 50 % higher in RIL (Table 4.20). These estimates were based on total skidding times per log of 39.03 min and 23.57 min for RIL and CL respectively per 8 m^3 per log, and assuming similar costs of owning and operating a D7F crawler bulldozer at RM127.00 hr^{-1} for the two techniques (Malvas, 1987). See Price (1989) for a fuller discussion of the accounting (chapter 8) and economic cost (chapter 9) of forest machinery. The labour cost was RM2 m^{-3} based on existing rate paid to the skidding crews in Parcel B.

The skidding cost for RIL of RM12.33 m^{-3} was higher than the supervised skidding costs reported by Marn *et. al.,* (1981) and Chua (1986) in Sarawak, Malaysia at RM6.09 m^{-3} and RM10.80 m^{-3}, respectively. The CL skidding cost of RM8.24 m^{-3} was lower than reported by Marn *et. al.,* (1981) at RM14.79 m^{-3} but higher than Chua's (1986) at RM4.71 m^{-3}. These differences were attributed to the different assumptions used in various valuations. For example, the load size for this study was larger at 8 m^3 per log compared to 4.74-8.77 m^3 in Marn *et. al.,* (1981) and 5.64-6.51 m^3 in Chua (1986). Another contributing factor to the difference in costs is the cost of owning and operating the bulldozer. The bulldozer owning and operating cost for this study was based on RM127 hr^{-1} whereas the two earlier studies used RM58.87 hr^{-1} and RM92.42 hr^{-1}, respectively.

RIL logging crews need to be compensated for their additional efforts and the longer non-productive working time (even once the learning curve has been overcome). The bulldozer operators often had to use greater skill in manoeuvering the bulldozer along narrow skid trails and dealing with hang-ups in the process of extracting a log. The role and the responsibility of the hookmen has changed under RIL since they have to assist the operator in deciding the best means of extracting a log in addition to making more use of the winch cable. The working hours were also longer than in CL. Based on a 50 % cost difference between RIL and CL techniques, the rate of pay for the RIL bulldozer operator and hookmen should be increased to RM1.95 m^{-3} and RM1.05 m^{-3}, respectively, from RM1.30 m^{-3} and RM0.70 m^{-3} in order to compensate for the lower earning due to RIL. The new rate of RM1.95 m^{-3} for bulldozer operator is still within the average rate reported for Sarawak at RM2.22 m^{-3} (Chua, 1986).

It is premature, however, to compensate the logging contractor as there is a need to supplement the present results with investigation on the economic cost of using a bulldozer in RIL and CL units. Price (1989; Chapter 9) has demonstrated that the cost of forest machinery varies with the rate of working. This approach as opposed to the traditional accounting method of depreciating machine on an annual basis could be a significant saving in RIL costs, given the longer idle time. The additional data to be

Table 4.20 Estimates of the hourly cost per timber volume for skidding operation

1 Assumptions

1.1	Volume per log	=	8 m^3/log
1.2	Machine cost	=	127.00 RM hr^{-1}
1.3	Labour cost	=	2.00 RM m^{-3}
1.4	Skidding cycle time		
	a) RIL	=	39.03 min/log
	b) CL	=	23.57 min/log

2 Cost calculation

2.1 RIL

$$\frac{127.00\ \text{RM} \times 39.03\ \text{min} \times 1\ \text{hr}}{1\ \text{hr} \times 8\ \text{m}^3 \times 60\ \text{min}} + \frac{2.00\ \text{RM}}{1\ \text{m}^3} = 12.33\ \text{RM m}^{-3}$$

2.2 CL

$$\frac{127.00\ \text{RM} \times 23.57\ \text{min} \times 1\ \text{hr}}{1\ \text{hr} \times 8\ \text{m}^3 \times 60\ \text{min}} + \frac{2.00\ \text{RM}}{1\ \text{m}^3} = 8.24\ \text{RM m}^{-3}$$

3 Increase in cost due to RIL

$$\frac{12.33 - 8.24}{8.24} = 49.66\ \%$$

collected and compared over the longer-term (at least one year) include bulldozer's consumption of fuel and oil; as well as the maintenance and repair costs due to wear and tear. In the absence of a fuller assessment, it remained debatable whether there would be savings or higher expenditure in RIL bulldozers' costs. Some could argue that there would be savings given the more efficient way of utilizing the bulldozer for skidding, avoiding unnecessary bulldozer movements and blading compared to CL. The logging contractors may contend that these potential savings are offset by the longer working hours and the more frequent uphill skidding, causing higher wear and tear.

4.3.4.3. Forest operation costs

4.3.4.3.1. Extraction costs

The RBJ's log extraction costs (including felling) for CL was RM72.92 m^{-3} which was calculated for the period 1992-1994 (Table 4.21). This represented the cost for CL in this study. Conversely, the log extraction costs for RIL techniques amounted to RM90.44 m^{-3} incorporating results of the felling/skidding time and motion study and using a harvest yield of 136 m^3 ha^{-1} (Table 4.22). The higher RIL extraction costs of RM17.52 m^{-3} or 24 % more than CL was due to two reasons. Firstly, RIL involved additional activities that cost RM6.20 m^{-3} more than CL. Secondly, the standard logging activities in RIL cost RM11.32 m^{-3} more than CL because of lower harvest yield.

The difference in results obtained per timber volume rather than per area can be illustrated by an example in the cost of road construction: the basis of payment for road construction is by linear distance at RM1,050 ha^{-1} and the costs per area did not differ between the logging methods. However, because of the reduced harvest yield in RIL, the unit cost would increase by 28 % (136 m^3 over 106 m^3) to RM9.91 m^{-3} against RM7.71 m^{-3} if based on CL's harvest yield.

For the second harvest, the extraction cost for RIL and CL increased to RM296.74 m^{-3} and RM239.25 m^{-3}, respectively. These represent a cost difference between treatments of about RM57.49 m^{-3}; tripled the cost difference for the first harvest. The main reason for such a difference between the first and second harvest was due to the effect of rising cost at 2 % annually over the projected duration of 60 years.

4.3.4.3.2. Log royalty

The actual expenditure on log royalty for the period 1992-1994 averaged RM55.20 m^{-3} (Table 4.21). The 1992 expenditure for this item at RM74.63 m^{-3} was much higher compared with the 1993 and 1994 rates at RM48.60 m^{-3} and RM42.38 m^{-3}, respectively.

Table 4.21 RBJ's actual expenditure on forest operations for the period 1992-1994

COMPONENTS	NOTES	1992	1993	1994	Mean	Values used in analysis (RM m^{-3})	
Cost of sales		RM m^{-3}	RM m^{-3}	RM m^{-3}	RM m^{-3}	CL	RIL
Log extraction fees	1	71.57	73.25	73.94	72.92	72.92	98.76
Royalties	2	74.63	48.60	42.38	55.20	40.00	40.00
Timber rights	3	4.40	4.34	15.02	7.92	7.92	10.14
Tug boat fees	4	1.34	1.58	3.80	2.24	2.24	2.24
SUB-TOTAL		151.94	127.77	135.14	138.28	123.08	151.14
Overheads							
General & administration	5	3.00	1.75	3.86	2.87	2.87	3.67
Remuneration &allowances	6	2.91	3.10	5.21	3.74	3.74	4.79
Financial charges	7	0.29	0.12	0.00	0.14	0.14	0.18
Management fees	8	5.12	5.15	10.68	6.98	6.98	8.93
Interest on timber rights	9	4.18	4.02	11.18	6.46	6.46	8.27
SUB-TOTAL		15.50	14.14	30.93	20.19	20.19	25.84
TOTAL EXPENSES		167.44	141.91	166.07	158.47	143.27	176.98

Source: RBJ, 1993 (Compiled in 1996)

1. Fees paid by RBJ to the logging contractor for log extraction operations (include logging activities at the stump down to the log pond)
2. Following the log export ban in 1993, the royalties for all locally processed logs are fixed at RM40 m^{-3} for all species
3. RBJ pays the Sabah Foundation fees for the right to extract timbers within the forest concession which is formulated based on the stumpage value
4. Hiring of tug boats for towing logs from the log storage pond to the shipside or mill
5. General and administrative expenses
6. Salaries, wages and allowances for forest workers
7. Bank charges on borrowed money
8. Fees paid to audit firms
9. Interests on the stumpage value

Notes:

a) Actual volume produced in 1992=2.87 million; 1993=2.91 million; 1994=1.4 million

b) Harvest yield factor: RIL harvesting cost would increase by a factor of 28% because of the lower harvest yield (Formulation: (136 m^3 divided by 106 m^3)

Table 4.22 Log extraction costs for RIL and CL techniques in ringgit Malaysia (RM) per volume of timber harvested and per logged area

Components	RM m^{-3}		RM ha^{-1} logged		Basis of payment
	RIL	CL	RIL	CL	
A Pre-harvest operations					
1 Coupe boundary survey and mapping	0.19	0.15	20.00	20.00	)
2 5% pre-felling inventory	0.24	0.18	25.00	25.00	)
3 Stock inventory*	1.35	n/a	143.01	n/a	) by area
4 Climber cutting*	0.63	n/a	66.77	n/a	)
5 Pre-harvest assessments*	0.23	n/a	24.83	n/a	)
6 Road alignment and marking*	0.07	n/a	7.86	n/a	)
7 Skid trail planning/marking*	0.22	n/a	23.34	n/a	)
Sub-Total	2.93	0.33	287.48	45.00	
B Harvest operations					
1 Road construction					
a) Main road	9.85	7.72	1050.00	1050.00	)
b) Secondary road	4.69	3.68	500.00	500.00	) by distance
c) Skid trail	4.72	3.68	500.00	500.00	)
2 Road maintenance	4.72	3.68	500.00	500.00	)
3 Felling					
a) Tree marking for directional felling*	0.91	n/a	96.92	n/a	)
b) Felling	2.20	1.30	233.20	177.00	)
4 Extraction	12.33	8.24	1306.98	1120.64	)
5 Bucking and scaling	1.28	1.00	136.00	136.00	) by volume
6 Loading/unloading	7.80	7.80	826.80	1060.80	)
7 Hauling	14.50	14.50	1537.00	1972.00	)
8 Rafting and barging	5.35	5.35	567.10	727.60	)
9 Log pond handling	1.39	1.39	147.34	189.04	)
Sub-Total	69.74	58.33	7401.34	7933.08	
C Post-harvest operations					
1 Drains and culverts*	0.38	n/a	40.00	n/a	) by units
2 Log landing amelioration*	0.05	n/a	5.00	n/a	) by area
3 Post-harvest assessments (2x)*	0.41	n/a	43.14	n/a	) by area
Sub-Total	0.83	0.00	88.14	0.00	
D Non-operational costs					
a) Staff salaries (field)	0.38	0.30	40.40	40.40	)
b) Staff salaries (headquarters)	0.90	0.70	95.45	95.45	)
c) Local travel	0.40	0.31	42.04	42.04	)
d) Vehicle maintenance	0.50	0.39	52.67	52.67	)
e) Office expenses	0.26	0.20	27.19	27.19	)
f) Consultancy and training*	1.46	n/a	154.57	n/a	)
g) Commission*	0.50	n/a	52.54	n/a	)
h) Capital assets	0.89	0.69	93.84	93.84	)
i) Service fees/other costs	11.67	11.67	1237.02	1587.12	)
Sub-Total	16.94	14.26	1795.72	1938.71	
Total	**90.44**	**72.92**	**9572.67**	**9916.79**	

Source: RBJ 1993 (Compiled in 1995)

i) RIL incremental costs are the summation of the difference between RIL and CL as itemized in A1,2; B1,2,3b,4-9 and D (a-e, h) .... 11.32 RM m^{-3}

ii) RIL investment costs include A3-7; B3a; C1-3; Df-g (with asterisks) 6.20 RM m^{-3}

iii) All unit costs include labour, machine and equipment costs. Machines used in RIL and CL sites were purchased at about the same time and owned by the same logging contractor, therefore, they have no differential costs.

iv) The unit costs (RM/m^3) are calculated based on the following harvest yield
RIL: (on actual area harvested) 106.00 $m^3 ha^{-1}$
CL: (on actual area harvested) 136.00 $m^3 ha^{-1}$

v) Main roads (B1.a) are constructed to 7 m width with adverse gradients of up to 15 degrees and gravelled to 25 cm thick. Roads in RIL and CL had the same specifications and were constructed prior to the start of the project.

vi) The hauling rate (B7) is RM0.29 $m^{-3} km^{-1}$. The total distance from stump to discharging point is taken as 50 km.

vii) Service fees include profits, infrastructure costs, fixed costs etc

viii) Where the actual activity costs of RIL are not available, the calculation was based on the cost of CL operations.

ix) RIL felling (B3) and extraction (B4) rates were based on results of the time and motion study.

The higher 1992 rate was because of the inclusion of the export royalty rate which was higher than the local processing rate. Since 1993, however, the royalty rate for all timber species processed locally was pegged at RM40 m^{-3}. This rate was used in the analysis of the first and second harvests.

4.3.4.3.3. Timber rights and tugboat fees

The actual expenditure on timber rights and tugboat fees for the period 1992-1994 averaged RM7.92 m^{-3} and RM2.24 m^{-3}, respectively (Table 4.21). The expenditure in 1994 for these two items were highest compared with the 1992 and 1993 expenditure due to lower production volume in 1994. The rates of RM7.92 m^{-3} and RM2.24 m^{-3} represent the rates for CL techniques in the first harvest. On the second harvest with CL, the rate for timber rights remained static, since this is paid per volume of timber produced, but the CL's tug boat fees increased to RM4.93 m^{-3} in view of the anticipated real price increase in the cost of materials (e.g. fuel, parts etc.) at 2 % annually. With RIL, the timber rights fee was adjusted for the lower harvest yield using the factor (CL_{yield}/RIL_{yield}). The outcome of this adjustment is that the RIL's timber rights fees for the first harvest is RM10.14 m^{-3}. The tug boat fee remained the same as the CL's rate (i.e. RM2.24 m^{-3}) because the fee is paid on per volume basis. For the second harvest, the timber rights fees remained the same as in the first harvest for same reason given above, but the tugboat fees increased to RM7.35 m^{-3}.

4.3.4.3.4. Operating overheads

RBJ's actual expenditure for the period 1992-1994 on overheads averaged RM20.19 m^{-3} (Table 4.21). The general overheads constituted only 13 % of the total cost expenditure for CL techniques. With the lower harvest yield in RIL, the overheads cost increased to RM25.84 m^{-3}. At the second harvest, the operating overheads for RIL and CL increased to RM84.78 and RM66.24 m^{-3}, respectively.

4.3.4.3.5. Summary of forest operation costs

The total costs of sales (namely extraction costs, log royalty, timber rights, tug boat fees and operating overheads) for the RIL and CL techniques for the first harvest were RM168.66 m^{-3} and RM143.27 m^{-3}, respectively (Table 4.23): RIL techniques cost RM25.39 m^{-3} or 18 % more than CL techniques. The higher RIL cost of sales was due to the higher log extraction costs, fees on the rights to harvest timber within the Sabah Foundation forest concession, and operating overheads associated with a lower production. The extraction costs for CL and RIL in the first harvest represent 54 % and 51 % of the total cost of sales.

Table 4.23 Summary of logging costs (RM m^{-3}) for RIL and CL techniques

	RIL	CL	RIL minus CL (RM m^{-3})	RIL minus CL (% of total CL)
Investment costs	6.20	0.00	6.20	4.33
Standard costs	84.24	72.92	11.32	7.90
1 Log extraction costs*	90.44	72.92	17.52	12.23
2 Other costs	78.22	70.35	7.87	5.49
Total of 1+2	168.66	143.27	25.39	17.72

*include felling, bucking, cross-cutting and skidding

At the second harvest, the RIL and CL costs increased to RM439.01 m^{-3} and RM360.77 m^{-3} (Table 4.24). The higher cost of RIL at RM78.24 m^{-3} or 22 % more than CL was attributed to the higher extraction costs, and operating overheads. Log royalty and timber rights did not contribute to the increase in costs for RIL and CL because they were held constant for the first and second harvest. As with the first harvest, the major cost component was the log extraction costs comprising 68 % and 66 % of the total RIL and CL cost of sales, respectively.

Three separate estimates are available of the industry average for purposes of comparison. The Timber Association Sabah (TAS) which represents the timber industry maintains that average log extraction costs were RM150 m^{-3} (ITTO, 1993). The Forestry Department of Sabah, however, reported a total log extraction cost of RM86 m^{-3}, an estimate supported by a 1991 World Bank report which placed average Sabah log extraction costs at around RM79 m^{-3}. Log extraction costs will inevitably vary as it depends on the hauling distance, terrain and forest types. However, it is clear that CL (RM72.92 m^{-3}) in this study had lower costs than all three estimates of industry average, and RIL (RM90.44 m^{-3}) was higher than two of the estimates.

4.3.5. Financial analysis

The financial implications of producing timber using RIL and CL techniques were investigated for first and second harvests. For the first harvest, the profits from RIL and CL techniques were RM27.34 m^{-3} and RM56.73 m^{-3}, respectively; the difference was RM29.39 (Table 4.24). The reduction of RIL profit to approximately half of CL's profit was due to higher costs and a lower production using RIL techniques. The additional RIL costs amounted to RM25.39 m^{-3} (RM168.66 m^{-3} minus RM143.27 m^{-3}) or 18 % higher than CL practices (Table 4.24). The bulk of the additional cost comprised the cost of extraction at RM17.52 m^{-3}

The economics of the second harvest (at end of year 60) was investigated under interest rates of zero (no discounting) to 10 %. Without discounting, RIL and CL techniques yielded RM223.31 m^{-3} and RM289.69 m^{-3}, respectively giving a difference of RM66.38 m^{-3} (Table 4.24). The reduction in profit due to the adoption of RIL was approximately 25 % of CL's techniques. At a 2 % discount rate, the net economic contribution for RIL and CL reduced to RM68.06 m^{-3} and RM88.29 m^{-3}, respectively; the difference of RM20.23 m^{-3} was smaller than without discounting. RIL had approximately 23 % less in profit margin. As the discount rate increased, the economic viability of both techniques weakened but continued to favour CL techniques. This phenomenon is associated with time discounting (Price, 1989) and implies that high interest rates emphasise the merits of short rotations and high yield crop (Leslie, 1987)

Table 4.24 Financial cost-benefit analysis for timber calculated on a per volume basis (RM m^{-3}) for CL and RIL techniques for first (at t_0) and second harvest (at t_{60})

	1st harvest at year 1	2nd harvest at year 60
A Revenue (RM m^{-3})		
i RIL	196 00	662.32
ii CL	200.00	650.46
B Cost of sales (RM m^{-3})		
1 Extraction costs		
i RIL	90 44	296.74
ii CL	72.92	239.25
2 Log royalty		
i RIL	40.00	40.00
ii CL	40.00	40.00
3 Timber rights		
i RIL	10.14	10.14
ii CL	7.92	7.92
4 Tugboat fees		
i RIL	2.24	7.35
ii CL	2.24	7.35
5 Operating overheads		
i RIL	25.84	84.78
ii CL	20 19	66.24
Total for RIL	168.66	439.01
Total for CL	143.27	360.77
C Proft before tax (RM m^{-3})		
i RIL	27.34	223.31
ii CL	56.73	289.69

D Financial indicators for the second harvest (year 60) discounted at rates between 0 and 10 percent

	0	2	4	6	8	10
Discount rate (%) ==>	0	2	4	6	8	10
Discount factor ==>	1	0.305	0 095	0.030	0.010	0.003
1 Net Present Value (NPV)						
i RIL	223.31	68.06	21.23	6.77	2.21	0.73
ii CL	289.69	88.29	27.54	8.78	2.86	0.95
2 Benefit-Cost ratio (BCR)						
i RIL	1.41	1.32	1 23	1.19	1.17	1 17
ii CL	1 69	1.57	1 47	1.42	1 41	1 40

E Sensitivity analysis (RIL: 2nd harvest)

		Net Present Value					
Discount rate (%) ==>		0	2	4	6	8	10
1 Price increased by	**10%**	289.54	88.25	27.52	8 78	2.86	0.95
	30%	422.01	128.62	40.12	12.79	4.17	1.39
	50%	554 47	168.99	52.71	16.81	5.48	1 82
2 Log grade increased by	**10%**	258.34	78.74	24.56	7.83	2.55	0.85
	30%	328.39	100.09	31.22	9.95	3.24	1 08
	50%	398.44	121.44	37.88	12.08	3.93	1.31
3 Cost decreased by	**10%**	262.20	79.91	24.92	7.95	2.59	0 86
	30%	339.97	103.62	32.32	10.31	3.36	1 12
	50%	417.74	127.32	39.71	12.66	4.13	1 37

Notes:

A) Revenue for second cut was based on the residual stockings in the CL and RIL units after first harvest. Log prices for second cut assumed to increase at real rate of 2 % per annum (ITTO, 1993)

B) Items B1,B4, B5 assumed to rise at a real rate 2.00 % per annum (Malaysian Producer Price Index, 1993) Cost items B2 and B3 are held constant over the forecast period.

D) Periodic discount formula. $\frac{1}{(1+i)^t}$ where t = 60, i = interest rates 0-10 percent

E1) Log price increase across all timber species

E2) Percentage of log grade for SQ was increased by a corresponding percentage increase in MQ grade

E3) Cost decrease applied to only extraction, tugboat and operating costs

The benefit-cost ratios (BCR) for CL and RIL techniques in the second harvest were greater than one; 1.16-1.41 for RIL and 1.39-1.69 for CL, signifying that both techniques yielded positive benefits. However, the BCR for RIL was lower than CL.

The lower economic benefit in RIL was due to two reasons: a higher extraction cost associated with leaving behind mature trees, and on a per hectare comparison, unrealized benefits of the better stocked advance regeneration within the time frame of analysis (60 years). For the latter, logging damage to trees in the 10-40 cm DBH class was halved in RIL units compared with CL units but these benefits might not have been realized within the time-span of this study (60 years). For example, trees of 10 cm DBH growing at 0.80 cm y^{-1} would grow into the harvestable size range (60 cm DBH) only after 63 years (Ong and Kleiner, 1996). The longer benefits on growth improvement (3rd cutting cycle) was not investigated in this study because simulation beyond 60 years was considered too inaccurate due to the technical limitations of *DIPSIM*. In addition, the effect of discounting reduces such longer-term benefits to very low net present value (Price and Willis, 1993) unless discounting is not applied.

4.3.5.1. Sensitivity analysis

4.3.5.1.1. Log price

The profitability of RIL was sensitive to log price changes. Without discounting, a 10 % increase in log prices across all species for the second harvest would improve the base NPV_{RIL} by approximately 30 % from RM223.31 to RM289.54 m^{-3}. The increase in NPV_{RIL} was almost at par with the NPV_{CL}. At a log price increase of 30 %, the NPV_{RIL} would doubled against the base case. A similar level of improvement was found with discounting although the NPV_{RIL} value was lower compared to without discounting due to the effect of discounting (Table 4.24). For example: at a 2 % discount rate, the base NPV_{RIL} of RM68.06 m^{-3} rose to RM88.25 m^{-3}; an increase of about 23 % with a 10 % change in log prices. Log prices increase of such a level or even higher has been demonstrated for the Asian countries because log prices can be volatile brought about by tightening supplies. For example, real prices of Asian tropical logs more than tripled in the first half of 1993 (ITTO, 1996). However, the improvement in RIL over CL with log price changes assumes that CL prices won't increase. This may or may not be the case depending on the supply and demand of logs.

Another potential source for price increase is via timber certification - a third party evaluation of timber sources from well-managed forest which provides access to market niches with premium price. One of the means to a well-managed forest is that the timber harvesting technology employed must be environmentally-friendly. A number of tropical countries, including Malaysia, have recognised the growing interest in certification and have responded with the development of national certification programmes compatible with ITTO's sustainable forestry guidelines. However, log price changes associated with timber certification would only affect timber from well-managed forest and not from conventionally logged forest.

4.3.5.1.2. Log grades

The NPV_{RIL} was also sensitive to changes in timber grade although in less dramatic effect compared with changes in log price. Without discounting, a 10 % improvement in SQ grades resulted in about 14 % improvement in NPV_{RIL}. With a 50 % improvement in SQ grades, the NPV_{RIL} was doubled (Table 4.24). If discounting was applied, identical levels of improvements in NPV_{RIL} were obtained since all effects are at year 60. Although log grade improvement is less effective than price change in affecting NPV_{RIL}, it is most easily achieved between the two because the gain is inherent in the RIL harvesting system. For example, the practice of directional felling and the avoidance of stacking trees on each other will produce trees with less handling damages. Similarly, the insistence on winching logs out from the stump during skidding also reduces unnecessary damage to the logs (*pers. obs.*). These factors affect the t_{60} revenues, in particular, because the quality of the timber from the next cut depends on the degree and extent of damage inflicted on the future crop trees during first logging. For the t_0 revenues, the difference in timber quality between the RIL and CL units was less critical, because timber was harvested from unlogged forest.

4.3.5.1.3. Costs

The effect of reducing the cost in two main activities namely, the extraction and operating overheads, also have significant improvement in the NPV_{RIL}. Without discounting, a 10 % reduction in these cost items would improve the NPV_{RIL} of the base case by 20 %. At 50 % reduction in costs, the NPV_{RIL} would double. With discounting, identical levels of improvements in NPV_{RIL} were found.

There are possibilities to reduce the extraction costs to improve the NPV_{RIL}. Firstly, log harvest planning could be confined to loggable areas only. This study found that unloggable areas in the RIL units accounted 44 % of the total logging area, and a 100 % stock mapping incurs unnecessary resources. Stock mapping (including the production of field map) costs RM1.35 m^{-3} or RM143 ha^{-1}, and is the most expensive activities among the additional activities required in RIL techniques (Table 4.22). However, there is a need to find an alternative means to determine which, in a given area, is loggable and unloggable prior to field work. Secondly, the non-operational costs include consultancy and training costs as well as brokerage commission for the pilot project. These are transaction costs in developing the RIL project which could be reduced or removed as RIL becomes more familiar to the forest enterprise (Table 4.22). Thirdly, there could be potential savings in RIL through reduction in machines' wear and tear from better-planned skid trails and harvesting techniques. The potential savings in extraction costs could be at least 10 %.

4.3.5.2. Financial analysis on a per hectare basis

For the first harvest, the profits generated from using RIL and CL techniques in harvesting timbers were RM2,912 ha^{-1} and RM7,715 ha^{-1}, respectively. The difference of RM4,803 ha^{-1} was due to a lower harvest yield using RIL techniques. The per hectare cost of extracting timber using RIL was cheaper than CL by RM344 (RIL= RM9,573 and CL = RM9,917; Table 4.22), but this is because the opportunity cost of forgone timber in RIL was not included in this costing.

For the second harvest, the NPV_{RIL} and NPV_{CL} without discounting was RM24,701 ha^{-1} and RM24,555 ha^{-1}, respectively. The cost difference between the two treatments was RM146 ha^{-1} favouring CL because of lower total RIL harvest (Table 4.25). At 2 % discount rate, the NPV_{CL} and NPV_{RIL} reduced to RM7,528 ha^{-1} and RM7,484 ha^{-1}, respectively, giving a difference of RM44 ha^{-1}.

4.3.5.3. Cost of forgone timber

The timber volume forgone in the RIL units at the start of the first rotation was estimated at 35 m^3 ha^{-1} after allowing 50 % for inaccessibility, cull and logging wastage. At a conservative profit margin of RM28.19 m^{-3}, the value of forgone timber would be equivalent to RM993 ha^{-1} and the overall economic scenario on RIL weakened further. However, a more detail analysis of the forgone timber will be dealt with in chapter 10.

4.3.5.4. Second and third economic scenarios

Given the second economic scenarios described in 4.2.3 in which CL is replaced by RIL in the second harvest, the NPV_{RIL} would remain the same as the base case but NPV_{CL} would reduce significantly. The reduction in NPV_{CL} is due to higher extraction cost as RIL techniques are adopted for logging CL units. The higher cost is also associated with low production volume since a significant proportion of timber would be forgone because of RIL imposed guidelines.

Table 4.25 Financial cost-benefit analysis for timber calculated on a per logged area basis (RM ha^{-1}) for CL and RIL techniques for first harvest (at t_0) and second harvest (at t_{60})

	1st cut at year 0					2nd cut at year 60
A Revenue						
i RIL	20,776					73,260
ii CL	27,200					55,133
B Cost of Sales						
1 Extraction costs						
i RIL	9,573					32,822
ii CL	9,917					20,279
2 Other costs (RM/ha)						
i RIL	8,291					15,737
ii CL	9,568					10,300
Total costs						
i RIL	17,864					48,559
ii CL	19,485					30,579
C Contribution						
i RIL	2,912					24,701
ii CL	7,715					24,555
D Financial indicators for one rotation (60 years)						
Discount rate (%) ==>	**0**	**2**	**4**	**6**	**8**	**10**
Discount factor ==>	1	0 305	0 095	0 030	0.010	0.003
1 Net Present Value (NPV)						
i RIL60	**24,701**	**7,528**	**2,348**	**749**	**244**	**81**
ii CL60	**24,555**	**7,484**	**2,334**	**744**	**242**	**81**
2 Benefit-Cost ratio (BCR)						
i RIL60	1 42	1 32	1.23	1 19	1.17	1 17
ii CL60	1.64	1.53	1 45	1.41	1.40	1.40

Notes:

A) Log prices assumed to increase at a real rate of 2 % per annum (ITTO, 1993).

B) Items B1 and B2 to rise at real r 2 % per annum (Malaysian Producer Price Index, 1993).

C) Discounting formula: $\frac{1}{(1+i)^t}$ where t = 60; i = interest rates 0-10 percent

D) Basis of calculating revenue and costs		1st cut at year Year 1	2nd cut at year 60	
a) Yield ($m^3 ha^{-1}$) per logged area	RIL	106.00	110.61	From Appendix 4.3
	CL	136.00	84.76	From Appendix 4.2
b) Costs (RM m^{-3})				
1) Extraction	RIL	90.44	296.74	From Table 4.23 & 4.24
	CL	72.92	239.25	From Table 4.23 & 4.24
2) Others	RIL	78.22	142.27	From Table 4.23 & 4.24
	CL	70.35	121.51	From Table 4.23 & 4 24
Total	RIL	168.66	439.01	
	CL	143.27	360.77	

Conversely, the NPV_{CL} in the case of the third scenario where RIL is replaced by CL in the second harvest will remain the same as the base case but the NPV_{RIL} would improved dramatically because of lower extraction costs using CL techniques and higher extraction volume from the logged area and area forgone for harvesting amounting to 44 % by area due to RIL imposed guidelines.

4.4 Conclusion

RIL was effective in reducing logging damage but was not economically attractive compared with conventional logging practices in hill dipterocarp forest in Sabah, Malaysia.

In extracting 9-13 trees of above 40 cm DBH, the overall damage inflicted on the residual forests averaged 60 % and 30 % in the CL and RIL units, respectively. The 50 % reduction in logging damage was achieved through the removal of climbers 8-12 months prior to felling; the practice of tree marking for retention of potential crop trees and directional felling; pre-harvest skid trail planning and RIL-imposed harvesting guidelines, e.g. restricting bulldozer movements to marked skid trails, limiting skid trail width, restricting felling in sensitive areas etc.

RIL was less attractive economically compared with CL for the first and second harvests. In the first harvest, the net contribution of RIL techniques was only one-third of CL's; improving to nearly two-third in the second harvest. The reasons for the lower NPV_{RIL} in the first harvest was due to high extraction costs, and a much larger volume of mature timber being left unharvested. The additional log extraction cost for first harvest amounted to RM18 m^{-3} . This was comprised of RM6.20 of investments in the additional activities of climber cutting, skid trail planning etc, and the additional cost of RM11.32 m^{-3} for the standard logging activities due to slower working to meet the RIL guidelines, as well as higher road cost per cubic metre because of lower yield. In the second harvest, the difference in log extraction costs between RIL and CL widened to RM58 m^{-3}, and was also the reason for the lower NPV_{RIL} compared to NPV_{CL}. The additional extraction costs and two other costs items (tugboat and operating overheads) had a significant impact on the NPV_{RIL} for the second harvest as indicated by the results of a sensitivity analysis. A 10 % decrease resulted in 20 % increase in NPV_{RIL}; a 50 % decrease in cost would double the NPV_{RIL}.

The NPV_{RIL} was most sensitive to log price increase; a 10 % increase would result in 23 % improvement in the NPV_{RIL} whereas a 30 % price increase would double the NPV_{RIL} relative to NPV_{CL}. The gain in NPV_{RIL} with a 30 % improvement in log grade was less significant compared with changes in log extraction cost and price increase.

Among the three variables (i.e. cost, price and timber grade), however, the improvement in log grade was most easily achieved because RIL techniques facilitate this achievement through proper felling and skidding techniques that inherently reduce log handling damages.

One of the hypotheses set out in the beginning of this chapter was that RIL at first harvest would lead to a much better grown, more valuable forest than CL by the time of the second harvest due to lower damage. This study found that the growing stock greater than 10 cm DBH in the RIL units was indeed higher than the CL units by approximately 10 % (RIL=624 trees ha^{-1}; CL=567 trees ha^{-1}, Table 4.16 and Appendix 4.1); and 31 % by volume (RIL=343 m^3 ha^{-1}; CL=260 m^3 ha^{-1}). The biggest savings on trees by using RIL techniques were found in the 20-40 cm DBH: this study found that they totalled 41 trees ha^{-1} (31 % difference between treatments) and 44 m^3 ha^{-1} (35 % between treatments). Although there was a higher growing stock in the RIL compared with CL-logged forest, the potential gains from the higher stocking of crop trees due to lower logging damage were not fully realized in the second harvest (Table 4.8). Presumably, trees in these diameter classes have not reached the harvestable size by the end of the 60 year simulation. It would require trees of 10 cm DBH to grow at a mean diameter increment of 1 cm yr^{-1} to reach a harvestable size of 60 cm DBH in 60 years. This is unlikely the case because growth rates for dipterocarps or non-dipterocarps species of 10 cm DBH are more commonly reported to be less than 1 cm yr^{-1}. For example, Rahman *et. al.,* (1992) based on a 10-year growth and yield data reported that the periodic diameter annual increment of dipterocarp and non-dipterocarp greater than 10 cm DBH in a tractor-logged forests in Pahang, Malaysia was 0.52 cm yr^{-1} and 0.30 cm yr^{-1}, respectively. Chew and Garcia (1994) reported that the mean diameter growth rate of all species greater than 10 cm DBH in a tractor-logged forest in Sabah was 0.56 cm yr^{-1}. On the other hand, Thang and Yong (1994) reported that diameter growth rate of dipterocarps and non-dipterocarps in Peninsula Malaysia for trees greater than 10 cm DBH was 0.60-0.69 cm yr^{-1}. Chai *et. al.,* (1994) reported that diameter growth rates for trees greater than 10 cm DBH for a selection of dipterocarps species in Sarawak was 0.30-0.43 cm yr^{-1}.

RIL harvesting practices resulted in about 44 % of the potential harvestable area being forgone. While such a volume of forgone timber may be welcome from the conservation point of view, it has adverse financial implications for RBJ given that these forests are to be managed for commercial use. It means having to cut a greater area of forest to make up for the shortfall in volume, thus exploiting the resource faster than planned. A win-win solution to this problem is to relax the RIL harvesting guidelines with particular reference to the slope restriction to access enclaves of harvestable trees and logging on steep slopes without adversely affecting the forest environments. This option is immediate, hence, allows RBJ time to improve the present techniques. It would also allow RBJ to investigate other technologies suitable for hill logging such as helicopter or skyline logging which have much lower density of skid trails (Blakeney, 1992; Arentz, 1992, Aulerich, 1995).

If the harvesting method for the second harvest in CL units was replaced by RIL techniques, it would cost more to log the CL units and there would be some timber forgone because of RIL-imposed harvesting guidelines. Consequently, the NPV_{CL} would reduce significantly. In another scenario where CL techniques would be the harvesting methods in both CL and RIL units, the NPV_{RIL} would be dramatically improved due to lower extraction costs using CL techniques, and a significantly higher extraction volume from first logged area and the 44 % area forgone in RIL units.

The economics of RIL imply some sharing of financial burden to promote the use of benign harvesting techniques for the long-term sustainable management of tropical forest (Leslie, 1987; Poore and Sayer, 1990). The RIL Project is a good example of such environmental cost-sharing where the costs were subsidized by NEES. A study by the ITTO has shown that approximately 90 % of the revenue derived from timber is realised by consumer countries (Oxford Forestry Institute, 1991). Out of that, 24 % is in the form of profits and 25 % is in the form of taxes collected by governments in consumer countries. This implies that a small change in taxation in consumer countries could be used to generate the funds required to cover the extra costs of good harvesting practices.

Chapter 5: Carbon

5.1 Introduction

There has been considerable discussion in recent times about the effects of global warming and the role of forests in mitigating global warming (e.g. ITTO, 1995). Global warming is caused by the presence of greenhouse gases which block the re-radiation of long wavelength radiation emitted by earth. This natural phenomenon is necessary to stabilise earth temperatures at levels suitable for life. However, an excess concentration of greenhouse gases in the atmosphere would increase warming to the detriment of the productivity and health of the world's ecosystems that are already under stress from current levels of population and economic activity (Schlaepfer, 1993). Among the greenhouse gases, carbon dioxide (CO_2) makes up the largest proportion and is expected to account for 55 % of the warming effect of greenhouse gases over the next century (Houghton, 1990).

The largest source of atmospheric CO_2 is from fossil fuel burning which accounts for 5.4 ± 0.5 Gt C yr^{-1} of world-wide emission (1 Gt = 1 billion metric tonnes of carbon = 1 x 10^{15} g C). Forest degradation resulting from human activities that removes natural forest cover entirely or partially also contributes to atmospheric CO_2 (Houghton, 1992). When forest is cleared and burned (deforested), there will be a sudden release of CO_2; some of the carbon that is locked up in lumber, ash and charcoal may also be released in later years. The amount of carbon storage loss by converting tropical forest to pasture or permanent agriculture is about three times that re-captured in secondary vegetation over one crop rotation (Brown and Pearce, 1993). It has been estimated that carbon released to the atmosphere due to deforestation world-wide alone accounts for 1.6 ± 1.0 Gt C yr^{-1} (Cline, 1992). Apart from deforestation, tropical forest also suffers from degradation by various forms of disturbance without involving clear felling that contributes to global warming. The most significant and widespread is that of selective logging in the tropical regions. During logging of tropical forest, commercial trees are selectively harvested and removed, trees not removed may be damaged and sometimes killed, and some deforestation occurs during construction of logging roads and log landings. There may also be a long-term change in species composition caused by continued removal of a few popular species. Trees removed or killed are a source of carbon flux to the atmosphere contributing to global warming. On the other hand, the residual forest has the potential to become significant carbon sinks through natural recovery processes (Lugo and Brown, 1992). The exact quantum of CO_2 released and sequestered by selective logging and its role in the context of the global carbon cycling is still unclear; being a relatively new interest compared with the impact of deforestation.

The annual emission of 6-7 ± 1.0 Gt C from fossil fuel burning and deforestation is less than 1 percent of the 750 Gt C stock of carbon contained in the atmosphere (Figure 5.1). The largest carbon sink is in the ocean which holds approximately 37,000 Gt C and annually emits 90 Gt C to the atmosphere and extracts about 93 Gt C from it. Tropical forests, which alone account for nearly 40 % of the world's total biomass (Brown *et. al.*, 1989) and 15 % of the soil carbon, are also important carbon sinks (Schlesinger, 1984). The rate of net CO_2 fixation in forests depends on various factors. For example, different forest covers and landuses have different CO_2 fixation capacity as summarised in Table 5.1. In general, young forests that experience net growth sequester CO_2 more actively than old growth forests. Carbon stored in trees may last many years depending on the timber species, site class and its utilisation. When timber is harvested, part of the carbon is stored for a long period of time in products such as buildings, furniture, and books (Figure 5.2). Part of the carbon is released as wood is burned for energy or as the harvest debris decay. Similarly, soil carbon is fixed and released in living organisms and dead organic matter (Brown and Pearce, 1993). It has been estimated that forest holds about 560 Gt C and the soil roughly 1,400 Gt C (Schlesinger, 1997). In the context of the global carbon cycle; plant and soil respiration and decay together emit about 120 Gt C to the atmosphere, while photosynthesis extracts approximately the same 120 Gt C from it (Figure 5.1).

The prospects of increasing atmospheric CO_2 fixation in forest biomass through forest management activities have been suggested by a number of authors (e.g. Myers, 1989; Sedjo, 1989; Thompson and Matthews, 1989; Houghton, 1990; Nordhaus, 1991; Cline, 1992; Brown and Pearce, 1993). These include increasing reforestation or afforestation programs; increasing wood growth in forests for timber production; increasing use of wood for energy in place of fossil fuels; improving wood utilisation etc. Carbon retention or fixation in forest biomass through reduction in logging damage is another forestry opportunity for mitigating global warming (e.g. Marsh *et. al.*, 1994). The rationale is that a properly logged forest retains many of the structural, functional, and compositional attributes of unlogged forest; biomass is retained and post-logging recovery rates are enhanced. This, in fact, is the primary motivation of the RIL project which employs RIL techniques as a deliberate modification of conventional methods of harvesting tropical timber to retain more carbon and slow the release of CO_2 (Jones and Stuart, 1994; Pinard *et. al.*, 1996).

The concept of the RIL techniques and their associated benefits has been discussed in previous chapters. This chapter deals with the carbon benefit with the aim of assigning an economic value for each tonne of carbon saved by RIL compared with CL

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as part of the overall economic assessment of RIL techniques. The investigation is restricted to CO_2 fixation in forest biomass at the stumpage area in order to describe the carbon benefit due to the impact of logging. The carbon fixed in end-use wood products such as furniture, paper, etc. are, therefore, of lesser significance in this study, although an important consideration in carbon analysis. In any case, the timber produced from both the RIL and CL units in the study area have the same end use. They are milled locally and most are exported as plywood or veneer to Japan and Korea; some sawn timber is produced and used within Malaysia. The chapter first sets out the basis and methodology for quantifying and valuing the carbon benefit. The results provide the basis for discussing the implications for the economic value of RIL; its cost-effectiveness against other forestry offset options; the choice of the economic model; and the potential for including RIL carbon offset as a joint implementation project under the UNCED Framework Convention on Climate Change (UNFCCC).

5.2 Methodology

5.2.1 Quantification of forest carbon benefit

The carbon benefit of interest to this study is the difference in carbon sequestered in the RIL and CL units for a 60-year rotation. The basis for taking the net carbon benefit or the 'incremental effect' between RIL and CL is relevant in the context of the climate change convention (Jackson, 1994). One of the rationales of the incremental effect is to separate forests or forest management practices that can be qualified as generating offsets. For example, forests to be logged by conventional logging practices cannot qualify for offset unless there is an explicit intention to improve the harvesting methods aimed at sequestering incremental carbon. Another example would be forests which have been previously gazetted as national parks, which may not qualify for offset because such forests were established for other reasons before the concept of carbon offset arose (Moura-Costa, 1996). The incremental effect is especially an important consideration in the discussion of funding the costs of greenhouse gas abatement which focuses on the incremental costs; namely, the costs of a particular mitigating strategy or measure over and above the costs that would have been incurred in the absence of that strategy or measure (Jackson, 1994). In this study, the carbon benefit in the CL units forms the baseline or reference scenario against which the incremental carbon benefit from implementing RIL is assessed.

The basic framework for estimating carbon in the study area involves the establishment of permanent field plots in the study area and inventorying the biomass and necromass in these plots before and after logging. This aspect of the field work was jointly supervised Dr Michelle Pinard and myself. The carbon data analysis was carried out by the latter. The carbon pools that were considered in this study included those stored in above-ground living biomass (e.g. trees, understory vegetation), below-ground living biomass or root biomass, soil carbon and other necromass including coarse woody debris, standing dead material, and coarse and fine litter. Following logging, a post-harvest inventory of the above- and below-ground biomass was conducted in the study area in order to estimate the residual carbon in the respective carbon pools.

The parameters for the above-ground biomass include trees over 1 cm DBH, lianes over 2 cm DBH, shrubs, herbs, palms and herbaceous vines. For trees and woody vines, their DBH are first measured and the volume calculated from regression equations and converted to a total biomass equivalent by multiplying by a biomass expansion factor (e.g. Kira, 1978). Biomass of smaller plants is determined by taking samples from clip plots, oven-dried and weighed. Soil carbon pools are estimated from the concentration of soil organic matter at the forest floor and root biomass to a soil depth of 50 cm. Detailed description of the experimental designs that were adopted for the pre- and post-logging biomass data for this study have been given in Chapter 3 and are summarised in Table 5.2 and 5.3. In this study, the unit for biomass and necromass is megagrammes per hectare (Mg ha^{-1}; metric tonnes per hectare).

The calculation of forest carbon pre- and post-logging in the RIL and CL units involves firstly, summing the amount of above- and below-ground biomass and necromass in a given area, and secondly; converting these estimates to carbon mass using appropriate conversion factors. Biomass and necromass estimates were converted to carbon mass equivalent (expressed in Mg C ha^{-1}) using conversion factors determined for the composition of biomass in this forest and for woody and fine litter necromass separately (biomass to carbon = 0.492; woody litter to carbon = 0.5; fine litter to carbon = 0.469; Pinard, 1995). Carbon estimates can be converted to CO_2 equivalent by multiplying by a factor of 3.65 which is derived from the molecular weight ratio of CO_2 to carbon (CO_2=44; C=12). The study assumes that net growth (or accumulation of biomass) is equivalent to carbon sequestration and that decomposition of necromass is equivalent to emissions of CO_2.

To explore carbon dynamics due to the effect of logging for the next 60 years after first harvest, a carbon simulation model was developed for this purpose and is known as the carbon recovery (*C-REC*) model. *C-REC* was developed by Pinard (1995) for tracking carbon flows (fixation and emission of carbon in forest growth) and stocks in units logged by RIL and CL techniques based on the assumptions listed in Table 5.4. The main features of the carbon recovery model (*C-REC*) have been described in

Table 5.2 Sampling design for pre-logging assessment of forest biomass (after Pinard, 1995)

	Components	Experimental design	Calculation
Above-ground	Trees • >1 cm DBH	• Sampled trees in 8 logging units (4 RIL and 4 CL); each unit is 30-50 hectares • Used nested plots of 5 sizes (40x40m; 20x40m;10x20m; 10x10m; 5x5m) for different tree sizes	1) Calculate tree volume from regression equations 2) Calculate biomass using basal expansion factor (BEF) developed for dipterocarps forest (Kira, 1978) 3) Wood densities at 12 % moisture content converted to dry weight by applying regression equation developed by Reyes *et. al.*, (1992). For non-dipterocarp, the conversion was based on an arithmetic mean of the known species (0.503 g cm^{-3}, N=48)
	Lianes	• Only sampled in 4 CL units within tree inventory plots (no inventory in RIL plots because lianes were cut 8-10 months prior to felling)	• Biomass of lianes >2 cm DBH was estimated from basal area using a regression equation developed for Venezuelan lianes species (Putz, 1983) • Assume 67 % and 87 % of total lianes biomass contributed to the necromass pool
	Shrub, herb, palm, herbaceous vine	• Sampled from 3 RIL, 3 CL units • 1 m^2 circular plots (n=15 per logging unit; N=45 per treatment) • All plant biomass (<1 cm diameter) clipped and weighed	• Sub-samples were oven-dried @ 70° to constant mass
Below-ground	Butt roots (Coarse roots that are directly beneath trees)	• Sampled from 14 partially uprooted trees (20-130 cm DBH) along roads and skid trails • Coarse roots >10 mm diameter within 1 m of the bole of the tree were separated from soil, cut into pieces <50 kg, washed, weighed, and sub-sampled for dry weight determination	• Butt root mass was log-transformed and used as a dependent variable in a regression equation with DBH as the independent variable • Total root mass is calculated by applying the DBH-butt root mass equation to trees in the plots and calculating the mean butt root biomass per hectare across the eight logging units
	Coarse roots (>5 mm)	• Sample from 8 logging units (4 RIL and 4 CL) • Sampled in pits 50x50x50cm • n=10 pits per logging unit; N=40 pits per treatment • Live and dead roots weighed and sub-sampled (N=56)	• Coarse and fine root biomass are expressed on a per hectare basis. The calculation excludes areas occupied by butt roots.
	Fine roots (<5 mm)	• n=10 cores per logging unit; N=40 cores per treatment • Sampled in cores of 5 cm diameter and 10 cm depth	• Only total fine roots mass values are obtained due to difficulty in differentiating live and dead roots • 2 cores from each sampling site were soaked in water and agitated. Roots collected were oven-dried and weighed

Table 5.3 Sampling design for post-logging assessment of forest biomass

	Components	Experimental design	Calculation
Above-ground	Trees > 1 cm DBH	• All tree inventory plots re-visited 8-12 months after logging	• Damage divided into 3 classes; • Destroyed (uprooted and crushed) • Snapped-off below crown • Other damage (crown, stems, bark or root) • Calculate: a) timber volume per hectare extracted, b) necromass from branches, leaves, stumps and butt roots of harvested trees, c) necromass from trees destroyed; and, necromass from damaged trees that died within the first 8-12 months after logging
	Shrubs/herbs on skid trails, log landings and roads	• Visited 1 year after logging • New samples taken from 3 RIL and 4 CL logging units • New 1 m^2 clip plots established • n=10 per logging unit; N=70 per treatment	• Same calculation as used in pre-logging assessment
Below-ground	Coarse root (Living and dead)	• Visited 3 months after logging • New samples taken from 2 RIL and 2 CL logging units • New 50x50x50m pits established(n=10 per logging unit; N=40 per treatment)	• Same calculation used in pre-logging assessment
	Fine roots	• No sampling done	• Assume that fine root mass 1 year after logging is similar to mass before logging

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Chapter 3 (section 3.2.1.2). The model works on annual time steps, reads-in eco-physiological data, does the necessary conversions/calculations and produces carbon reports per one hectare of logged forest (Figure 5.3). A logging module reads in three parameters: timber volume extracted, the proportion of area with soil disturbance, types of tree damage classified into fatal (crown snap-off; destroyed) and minor damage (stem, bark, crown). Carbon storage is determined as trees grow, shed litter, die and are replaced based on assumptions of photosynthetic rates, transition probabilities between canopy layers, recruitment, and mortality rates. Carbon emission is tracked by the model and calculated based on tree respiration and decomposition rates. Carbon in living biomass is transferred to necromass and soil organic matter pools through tree mortality, litterfall and wood debris decay. Necromass decomposition in wood is calculated proportionate to total necromass using different values for coarse, small woody and fine litter debris. Carbon is lost from the soil organic matter pool at a rate of 5 % mass loss per year (Yoneda *et. al.,* 1977; Kira, 1978). Carbon stored in roots, shrubs, herbs, vines, and in mineral soil below 50 cm is not included in the model and is assumed equal in RIL and CL because they form only a small proportion of the carbon pool, and there is no evidence of any significant RIL minus CL difference (Pinard, 1996). This study uses the carbon data and simulation results produced by Pinard (1996) for the economic analysis.

5.2.2 Estimating the project costs

The additionality or incremental cost concept was applied in this study. The incremental cost is simply the difference between the total logging costs between RIL and CL techniques. The bases and calculations of these costs have been covered in chapter 4 (section 4.2.2.4) and summarised in Table 4.22.

5.2.3 Step 3: Estimating forest carbon value

There are two main approaches that have been used to calculate the carbon value or costs of greenhouse gas abatement; the 'damage-avoided' and the 'offset' approaches (Upton, 1994). The damage-avoided approach estimates the value of a tonne of carbon as being equal to the value of damage that would have been caused if the carbon were not sequestered. Examples of this approach are given in Nordhaus (1991) and Cline (1992) who valued the global warming damage as a percentage value of the global gross world product for a cross-section of economy. The 'offset' approach sets the value of carbon sequestration as equal to the cost of offsetting CO_2 emissions by investing in CO_2 reduction technology (e.g. Moulton and Richards, 1990; Schroeder *et. al.,* 1993). RIL falls under this category because the value of the carbon to be sequestered would be offset by the cost of modifying CL practice. For the 'offset' approach, there are three

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variations of techniques that have been used to calculate the unit cost for a tonne of carbon offset (expressed in terms of dollars per tonne of carbon - \$ tC^{-1}). These are the flow summation (FS) method, the average or mean carbon storage (MCS) method and the annualised-discounting method (Flow-NPV_{CO_2}). They differ mainly in respect of how carbon benefit is treated i.e. as carbon flows or stocks and whether discounting is applied. A brief description of each of these techniques follows based on the account of Richards and Stokes (1994).

The FS method sums the total tonnes of carbon captured for each year over the crop rotation regardless of when the capture takes place and divides this into the costs to give the carbon value; the annual carbon fluxes are expressed in tC yr^{-1} and their summation for the full rotation gives tC. The method treats early capture of carbon as equal to late capture of carbon, and is suitable for evaluating on offset option where the carbon gained is relatively constant over the future such as in forest plantations where it has approximately even growth (e.g. Richards and Stokes, 1994).

The MCS method expresses carbon in terms of storage rather than flows. The carbon storage on site is calculated as $\sum_{i=1}^{n} C_i / n$ where, C_i is the standing carbon tonnes in year *i*, and *n* is the rotation length. The total carbon storage (in tC) is obtained by summing the mean carbon storage for a period (e.g. annually) over one full rotation. The group of studies that employ the MCS assumes that all carbon is released upon harvest and the forestry practices are repeated in subsequent rotations (e.g. Dixon *et. al.*, 1993). This approach acknowledges the time factor and the different capture of carbon over the crop rotation but is difficult to compare with similar projects at different time periods (Richards and Stokes, 1994).

The Flow-NPV_{CO_2} method recognises that forest carbon is an irregular flow over time. In order to differentiate carbon benefits and costs according to when they are incurred or captured and to make different flows varying over time comparable, discounting is applied. Two approaches yield identical results. The first is to annualise the present value of costs over the period of carbon flows and to divide by the annual carbon capture rate (see Formula 1 below). The second approach is to discount the tonnes of carbon captured back to a summary statistic to give the *present tonnes equivalent* (PTE) and divide that figure into the present value of costs (Price, 1990; see Formula 2).

$$\frac{NPV_{cost} \times r \times \frac{(1+r)^T}{(1+r)^T - 1}}{\text{Carbon flow (annual)}} \quad \text{.... Formula 1}$$

$$\frac{NPV_{cost}}{\sum_{t=0}^{t=T}[\text{Carbon flow}]_t \ x \ \frac{1}{(1+r)^t}} \quad \text{.... Formula 2}$$

where r is the interest rate, T is time at rotation age and t is time within T.

The Flow-NPV$_{CO_2}$ method involves discounting although the rationale for discounting climate change is still being debated at large. Hoen and Solberg (1993) justified discounting climate change on the basis that a marginal reduction in atmospheric CO_2 (as a commodity which is contributing to the total welfare of the society) is assumed to increase the total utility of the society and must, therefore, be discounted at the social rate of discount. The social rate of discount is based on the assumptions that (1) the general welfare increases over time and (2) the marginal utility of income is decreasing with increased welfare. Richards (1993) demonstrated that the relationship between atmospheric greenhouse gas stocks and environmental damages is linear, which necessarily leads to a shadow price of atmospheric gas stocks that is constant over time. Under such circumstances, Richards suggested that it is justifiable to apply "normal" discounting in assessing climate change. Cline (1992) justified discounting climate change on the basis that benefit-cost analysis of policy response to the greenhouse effect requires inter-temporal comparisons over extremely long horizons; the discount rate is the key to address such long-term environmental effects and costs.

On the other hand, the relevance of discounting to climate change, and natural resources generally, has been challenged by Broom (1992) and Price (1993). The main arguments against discounting with reference to climate change are highlighted by Price and Willis (1993) and Price (1997) as follows:-

- There is still great uncertainty about the interaction of carbon sources and sinks as well as the effects of fertilisation by elevated CO_2 that leads to doubts about present perception of a simple negative exponential curve to represent the residence time of atmospheric CO_2 (Price and Willis, 1993; Price, 1997). The uncertainty of climate change with respect to atmospheric CO_2 emission and uptake and its consequence is a reason for increasing weight on the future rather than less weight as implied by discounting.
- Carbon fluxes may become less significant through time if technologies evolve for reducing atmospheric concentrations or the effects of concentrations (Price and Willis, 1993). New technologies' advance may, however, increase aggregate consumption per head of energy from all sources. For example, changing timber to steel would consume 430 times more energy in production, concrete nine times more energy and plastic 58 times.

- When costs of global warming are proportional to gross world product, and if population is growing as fast as production, the value of losses from climate change cannot be discounted for diminishing marginal utility – the most defensible general case for discounting.
- Time preference understood as preference for now over past or future rather than preference for early rather than late provides no justification for discounting within any time frame.
- Time preference has implications for inter-generational equity which is opposed to the concept of pure time preference i.e. present generations prefer their own consumption to that of future generations. Future generations will prefer their own consumption to that of the present, as present generations prefer their own consumption to that of the past.
- Discounting assumes that revenues obtained early (e.g. from carbon taxes) may be reinvested at interest to compensate for future costs. However, doubts have been expressed whether reinvestment would operate in practice and in most cases reinvestment of early revenues is only partial (Price, 1997).

While the magnitude of climate change effects depends on physical systems and social adaption, the economics of climate change over a long time-scale depends on the discount rate especially when there is a significant lag between abatement costs and the later benefits of avoided global warming (Cline, 1992; Price, 1997). For example, the benefits of burning fossil fuels are immediate; the consequences of releasing CO_2 are cumulative over centuries. The discount rate holds the crucial balance between the two as has been demonstrated by Price and Willis (1993). At the interest rates of borrowed money from commercial banks, effects in a hundred years have virtually no importance, and unabated greenhouse gas emissions seem justified. At lower-than-customary discount rates, the importance of carbon fluxes relative to timber revenue is little affected by general reduction of discount rate as demonstrated by Price and Willis (1993). Cline (1992) discounted climate change at a social rate of time preference (the rate at which society evaluates future consumption versus consumption today) of 1.5 %. The SRTP is based on the rate of growth of per capita income (1 %) multiplied by the absolute value of the elasticity of marginal utility of consumption (1.5) on the basis that it is the rising level of consumption that makes the 'marginal utility' of future income worth less than that of income received today and therefore provides the underlying rationale for discounting future consumption. Richards and Stokes (1993) used a social rate of discount of 5 %.

The valuation method that was selected for this study is appropriately the 'offset' approach because the value of carbon sequestration from RIL is offset or equal to the investment cost required to upgrade conventional harvesting practices to RIL. The economic model will necessarily be linked to time because the aim of the study is to evaluate the carbon value over one full rotation of 60 years after logging. The carbon benefit is also anticipated to be uneven over time because selectively logged tropical forests exhibit an uneven structure (Appanah *et. al.*, 1994). In view of these, the approach taken is to discount the tonnes of carbon to give the *present tonnes equivalent* (PTE) in order to make varying benefits over time comparable. A range of discount rates is used for this analysis (0 to 10 %) to illustrate how it affects the outcome of the valuation. The analysis also provides 20- and 40-year snap-shots of the carbon sequestration value and discusses their implications if carbon is treated as a stock or flow benefit. The Flow-NPV_{CO_2}, FS and MCS models were compared to identify the merits and demerits of each model.

This chapter makes no attempt to include the opportunity cost of forgone timber harvest, hence carbon sequestration benefit, due to RIL. The forgone carbon sequestration benefit will be dealt with in chapter 10.

5.3 Results

Logging affects the pre-logging biomass and necromass by removing biomass in timber; converting biomass to necromass; influencing the rate of decay of necromass, and rate of increase in biomass (Figure 5.4). Firstly, the net changes in biomass (above-ground, below-ground) and necromass stocks that were measured in the field are presented. This section provides the necessary data input for projecting biomass and necromass stock over the 60 year rotation. Next, the projected net changes of biomass stocks (including extracted timber) and necromass in general terms are examined. This second section has two sub-sections; the first examines the biomass and necromass stock and the second presents changes in biomass stock only (excluding necromass stock) to compare forest recovery rates with chapter 4 (i.e. compare the results produced by the two models C-REC and DIPSIM). Finally, the last section presents the projected carbon stock and flows including those above-ground, below-ground, in extracted timber and in necromass pools.

5.3.1 Measured biomass and necromass stocks

The pre-logging above-ground and below-ground biomass in the CL and RIL logging units was similar in the two areas ($mean_{nl}$=399 ± 20SE Mg ha^{-1}; $mean_{nl}$=394 ± 30SE Mg ha^{-1}; Table 5.5). Above-ground biomass comprised approximately 83 % and below-ground 17 % of total biomass content for the two experimental units.

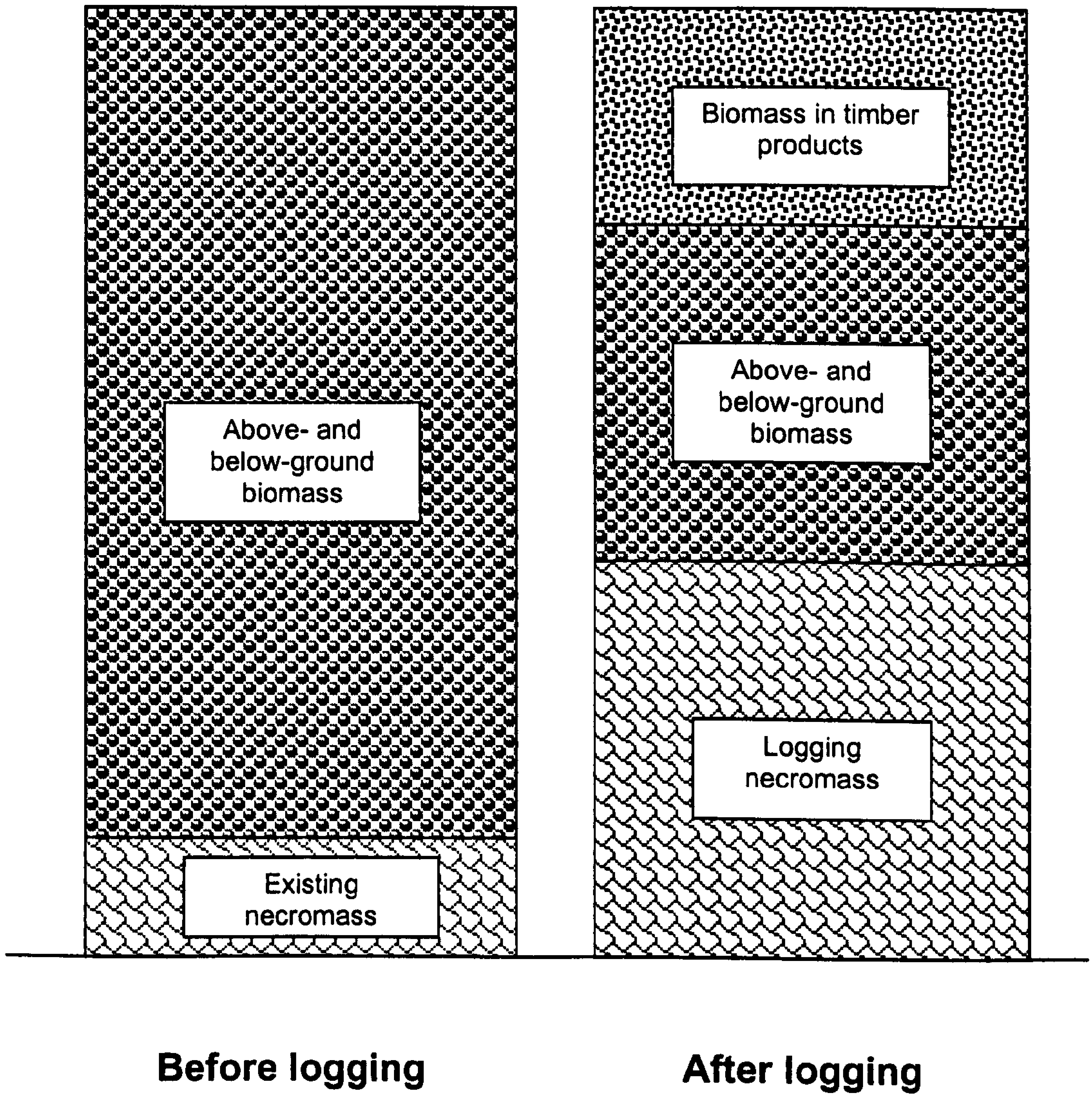


Figure 5.4 Components of biomass and necromass pools being examined before and after logging in the RIL and CL study area

Table 5.5 Stock and flow (± standard error) of biomass and necromass before and after logging in the RIL and CL units

Timing	Biomass (Mg ha^{-1})		$^{+}$Carbon (Mg C ha^{-1})	
	CL	RIL	CL	RIL
Before logging	399 ± 20	394 ± 30	196 ± 10	194 ± 15
After logging (8-12 months)	176 ± 17	264 ± 20	87 ± 8	130 ± 10
Removed/destroyed	223	130	110	64
*Extracted as timber	31 ± 4	22 ± 5		
Logging debris/killed	192 ± 18	108 ± 11		

Note: * Extracted timber excludes 50 % left on site as debris converted to necromass
+ Conversion factor for biomass to carbon is 0.492 (Chan, 1982)

One year after logging, total biomass in the CL and RIL areas dropped to 176 ± 17 (SE) Mg ha^{-1} and 264 ± 20 Mg ha^{-1} or 44 % and 66 % of the original biomass, respectively. RIL units contained 86 ± 22 Mg ha^{-1} or 50 % more residual biomass than conventionally logged areas.

The biomass stocks that were removed from the RIL and CL units to be converted into timber products were approximately 22 ± 5 Mg ha^{-1}, and 31 ± 4 Mg biomass ha^{-1}, respectively (Table 5.5).

The total necromass produced from CL units in the form of logging debris and trees killed was 192 ± 18 Mg necromass ha^{-1} (including 50 % of extracted timber). In contrast, total necromass produced in the RIL units amounted to 108 ± 11 Mg ha^{-1}; barely half the amount produced in the CL units (Note: this necromass figures exclude pre-logging or existing necromass in the RIL and CL units which approximates 39 tC ha^{-1} [Pinard, *pers. comm.*]. The existing necromass is not relevant if the interest is to compare the RIL and CL effects, but is needed for comparison with unlogged forest).

5.3.2 Projected biomass and necromass stocks

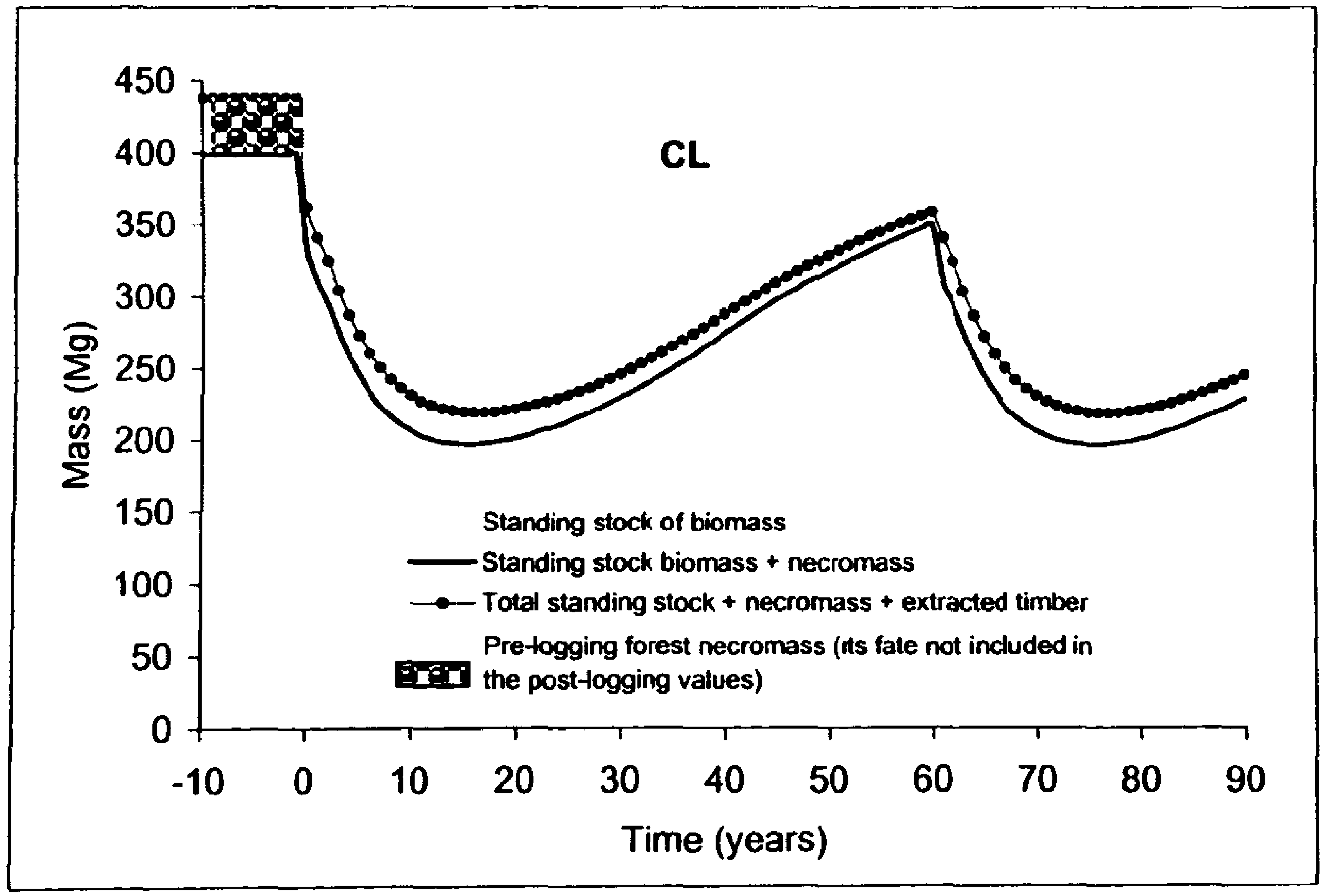
The projected changes in biomass and necromass stock (and in carbon stock) in the RIL and CL units following logging were based on the assumptions given in Table 5.4. The results are as follows:

5.3.2.1 Changes in biomass and necromass

The initial total biomass in the RIL and CL units were 394 and 399 Mg ha^{-1} in the RIL and CL units, respectively (Figure 5.5). Following logging in the RIL and CL units, the initial biomass levels drop to 264 and 176 Mg ha^{-1}, respectively. The decline in biomass stock was less severe in RIL than in CL. The general trend of biomass recovery in RIL and CL units is that there was little change in post-harvest biomass for the next 10-15 years. After this period, the biomass stock begins to increase and accumulates to approximately 383 and 310 Mg ha^{-1} for RIL and CL, respectively by year 60.

RIL extracted approximately 43 Mg ha^{-1} of biomass while CL extracted 61 Mg ha^{-1} of biomass out of the total forest biomass in the two units, respectively. However, for both RIL and CL, it was assumed that 50 % of these biomasses were left on site, and the remaining removed from site and converted into timber products.

Total necromasses (excluding pre-logging necromass) produced from logging in the RIL and CL units were approximately 109 and 192 Mg ha^{-1}, respectively.



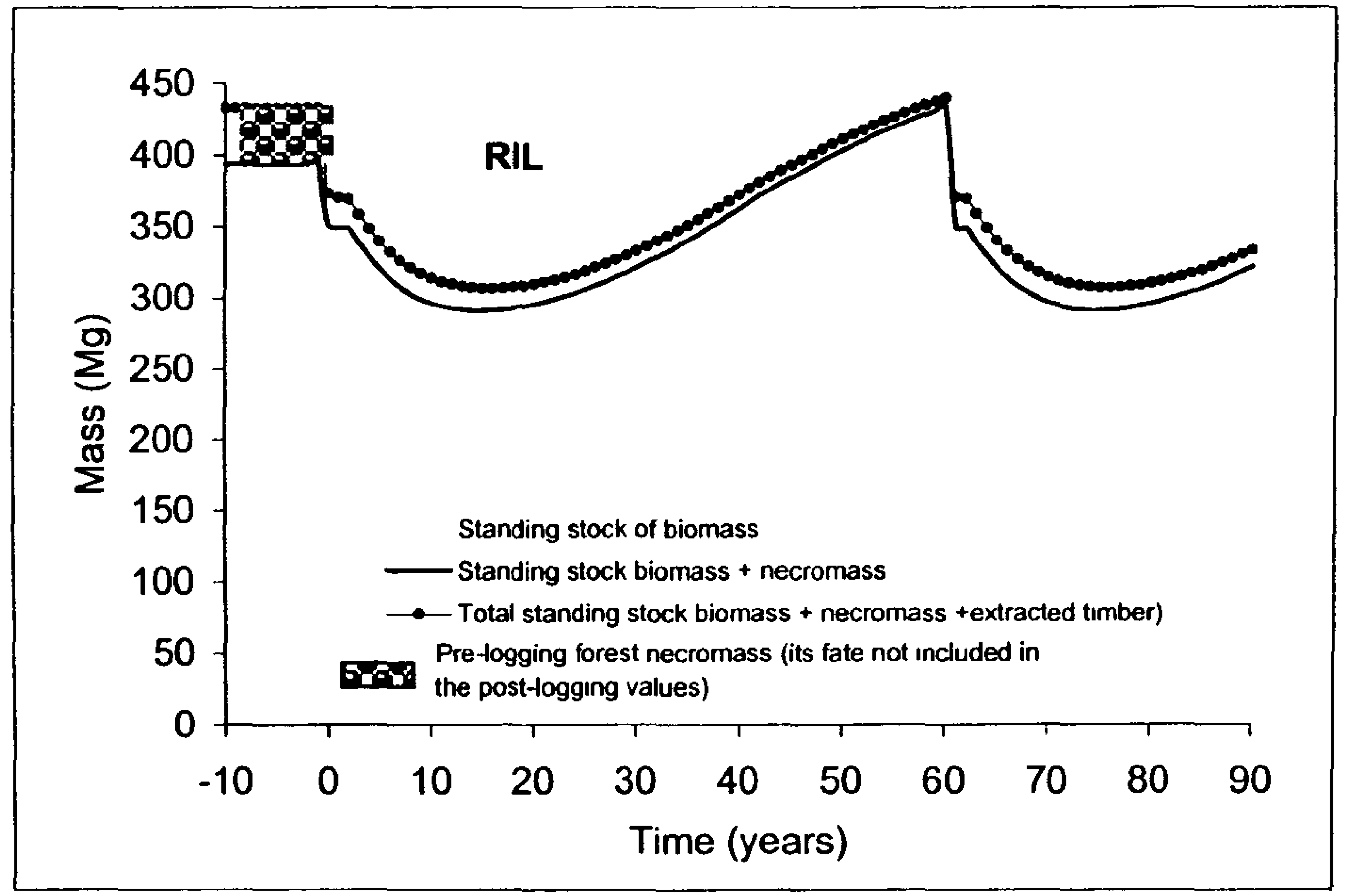


Figure 5.5 Change in mass (biomass and necromass) stocks for CL and RIL units. The initial biomass for the RIL and CL units was 399 and 394 Mg ha^{-1}. Following logging, the biomass and necromass dropped to 176 and 268 Mg ha^{-1}. Logging removed approximately 63 and 41 Mg ha^{-1} of biomass in extracted timber (50 % of this was removed from the study area and locked-up in timber products) and produced a total of 192 and 109 Mg ha^{-1} of necromass in the CL and RIL units, respectively (Pinard, *unpubl*). The carbon mass equivalent (tC ha-1) for these values can be calculated by multiplying by a conversion factor of 0.492 (Chan, 1982)

Following logging, the post-harvest biomass and necromass in CL units continued to drop until year 15 before it began to recover. The recovery profile for RIL units exhibited a similar trend to the CL units, but differed in two aspects: the decline was less steep and recovery started earlier at year 12 (Figure 5.5). The total biomass and necromass in RIL and CL units accumulated to approximately 433 and 351 Mg ha^{-1}, respectively by year 60. RIL exceeded the pre-logging stock of 399 Mg ha^{-1}.

At t_{60}, the remaining necromass in the RIL and CL units were approximately 48 and 38 Mg ha^{-1}, respectively. These represent 54 % and 24 % of the year one necromass stock in the two areas, respectively. The faster volatilisation rate in the CL units may be associated with the more opened canopy that increased biotic and abiotic factors in above-ground litter decomposition (e.g. Burghouts *et. al.* 1992).

The total biomass and necromass stocks including extracted timber for RIL and CL units at pre-logging was estimated to be approximately 433 and 438 Mg ha^{-1}. Assuming a volatilisation rate of 3 % for timber products (the minimum value used by Thompson and Matthews, 1989), the total biomass and necromass stock in RIL and CL units by year 60 were 434 and 352 Mg C ha^{-1}. This gives a RIL – CL difference of 82 Mg ha^{-1} at the end of 60 years.

5.3.2.2 Changes in biomass

The projected changes in above- and below-ground biomass in the RIL and CL units associated with logging showed that the initial biomass of 399 and 394 Mg ha^{-1}, respectively, dropped to 264 Mg ha^{-1} and 176 Mg ha^{-1} (Figure 5.5). The drop gradient for the RIL units was less sharp than that for CL units. RIL units also recovered more quickly from the logging disturbance.

These post-harvest levels showed little change for a number of years in both study areas until about year 15 for CL and year 12 for RIL when biomass began to increase. The recovery pattern in the RIL units differed from CL units in that post-harvest decline in biomass was less severe and of shorter duration. Once passed this recovery phase, the biomass in the RIL and CL units increased steadily and accumulated to 383 Mg biomass ha^{-1} and 310 Mg biomass ha^{-1}, respectively by year 60. These levels are below the pre-logging levels of 394 and 399 Mg biomass ha^{-1}. The RIL – CL difference in biomass over 60 years was 73 Mg biomass ha^{-1}.

5.3.3 Projected carbon stock and flows

5.3.3.1 Carbon stock

The total carbon stocks in the RIL and CL units were 213 and 216 Mg C ha^{-1} (Figure 5.6). These were calculated by converting biomass and necromass stock to carbon mass by multiplying by the factor 0.492 (mean values of three factors – see page 165). These stocks include 11 and 15 Mg C ha^{-1} of carbon mass from the RIL and CL units that were stored in timber products. Logging also produced a total necromass of approximately 53 and 94 Mg C ha^{-1}.

By year 60, the total carbon stocks in the RIL and CL units were 214 and 174 Mg C ha^{-1}, respectively (Figure 5.7) The difference in mean carbon storage between the study areas was approximately 40 Mg C ha^{-1}.

5.3.3.2 Carbon flows

The projected annual carbon flow was calculated by deducting the current year stock from the previous year stock for the study areas. In both the RIL and CL units, the flows were negative for as long as 17 to 18 years following logging. This implied that carbon emission rates were higher than fixation rates in the early years of forest recovery from logging disturbance. After this period, the forests began to sequester carbon. By year 40, there was a slight decline in carbon sequestration in the two study areas.

The annual relative net gain in carbon flows (fixation minus emission) between the RIL and CL units was high for the first 10 years with a mean of 4 Mg C yr^{-1} (Figure 5.8). The main reason for this early gain was the net change in biomass and necromass pools before and after logging. After this point, both types of forest began to recover and annual net carbon gain recorded was less than 1 Mg C ha^{-1}. The cumulative totals of carbon flows in the RIL and CL units were 0.6 and -42 Mg C ha^{-1}, respectively (Appendix 5.1). The net difference in carbon flow between the RIL and CL units was 42.6 Mg C ha^{-1}.

5.3.4 Cost of logging

The total costs of employing RIL to harvest timber as established in chapter 4 (Table 4.24 and 4.25) amounted to RM9,573 ha^{-1} (RM90.44 m^{-3}) while CL costs RM9,917 ha^{-1} (RM72.92 m^{-3}). RIL was cheaper per hectare by RM344 because of the smaller volume logged compared to CL, but more expensive per cubic metre by RM17.52 because of

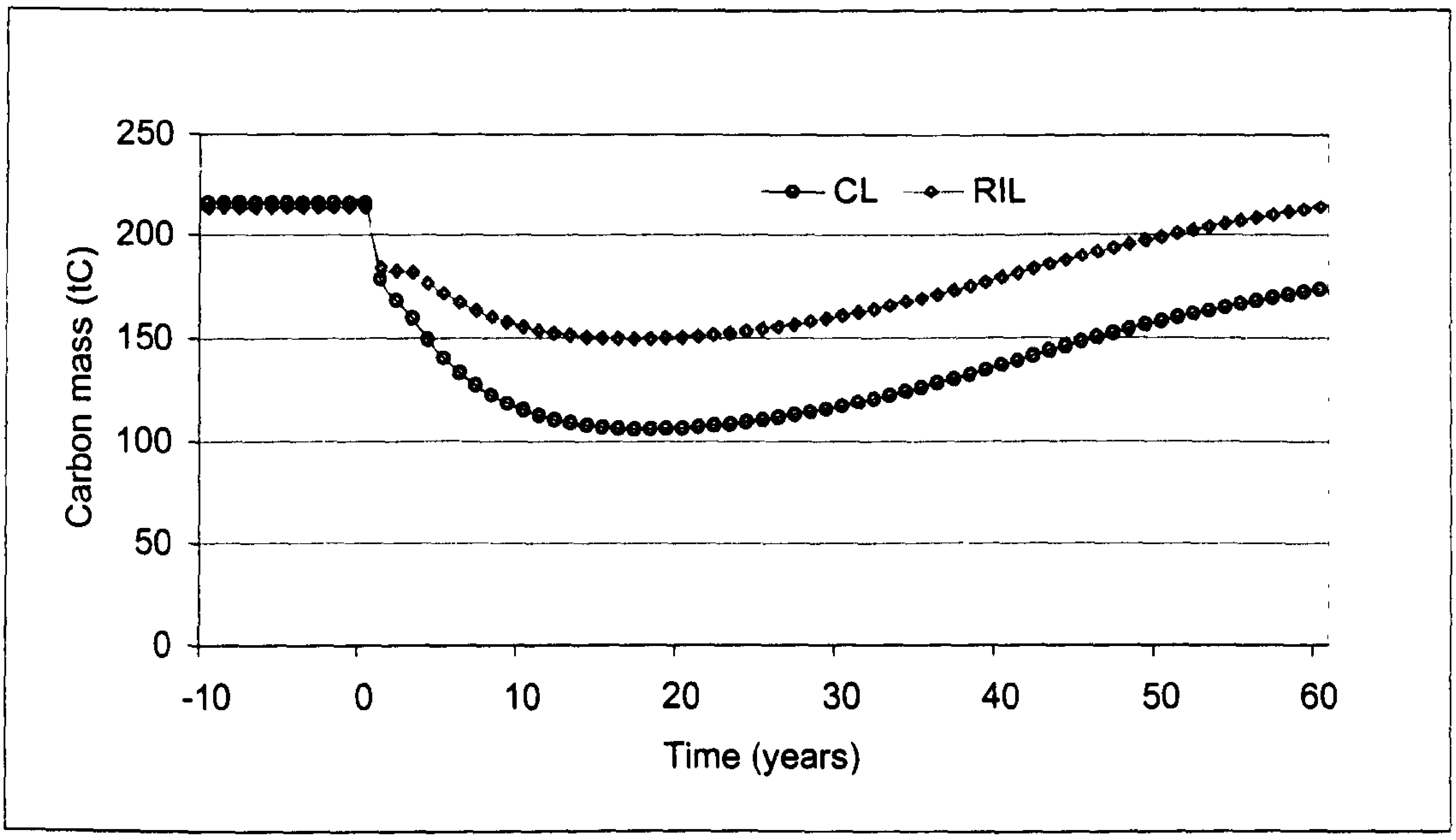


Figure 5.6 Projected carbon mass and necromass in forests logged by CL and RIL techniques over 60 years based on assumptions given in Table 5.4 (profiles also include approximately 15 tC ha^{-1} for CL and 11 tC ha^{-1} for RIL that are stored in timber products, and are assumed to decay at 3 % per year)

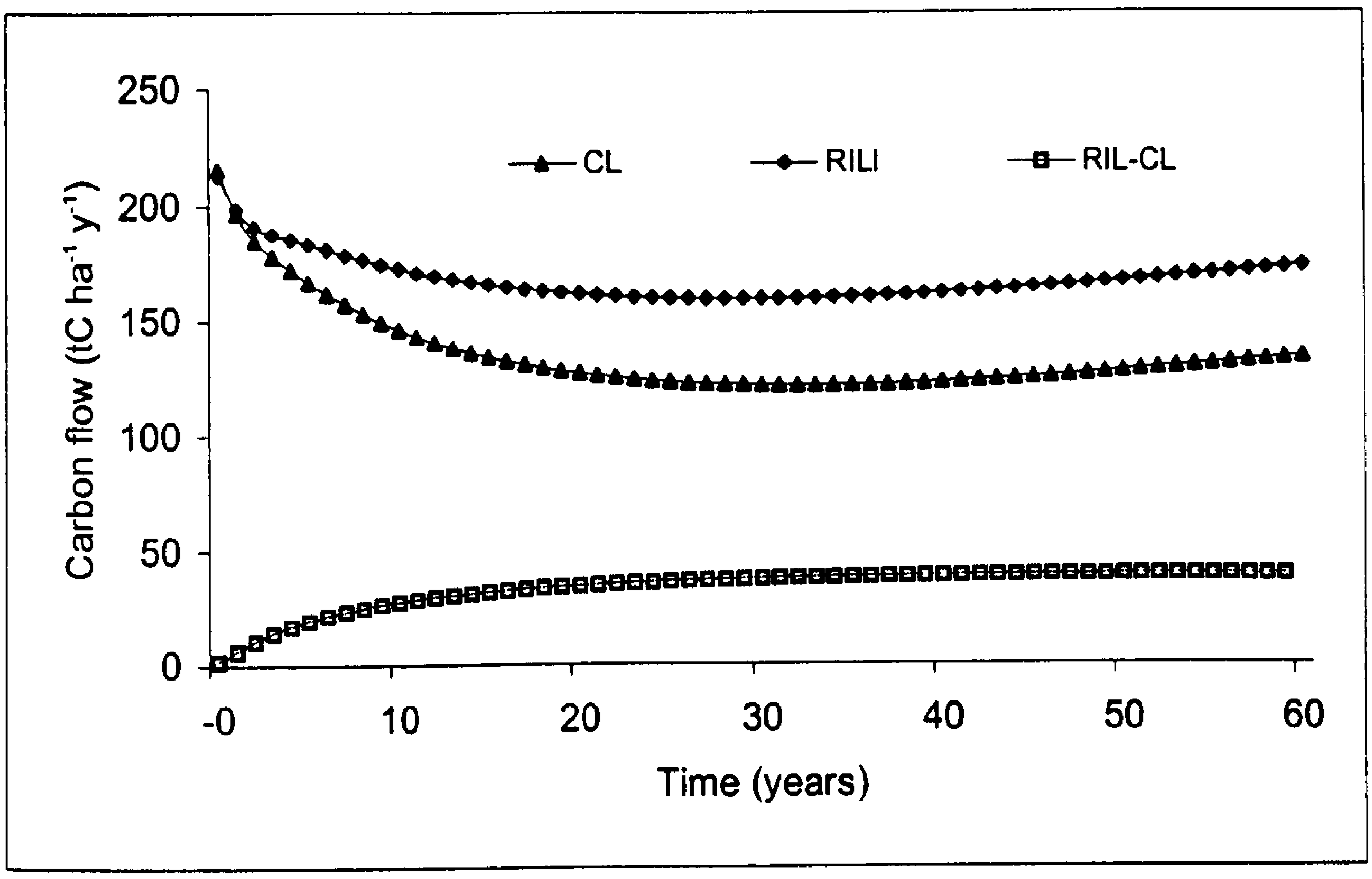


Figure 5.7 Mean carbon stock (tC ha^{-1} y^{-1}) from forest logged by CL and RIL techniques (Source of data from Pinard, *unpubl.*)

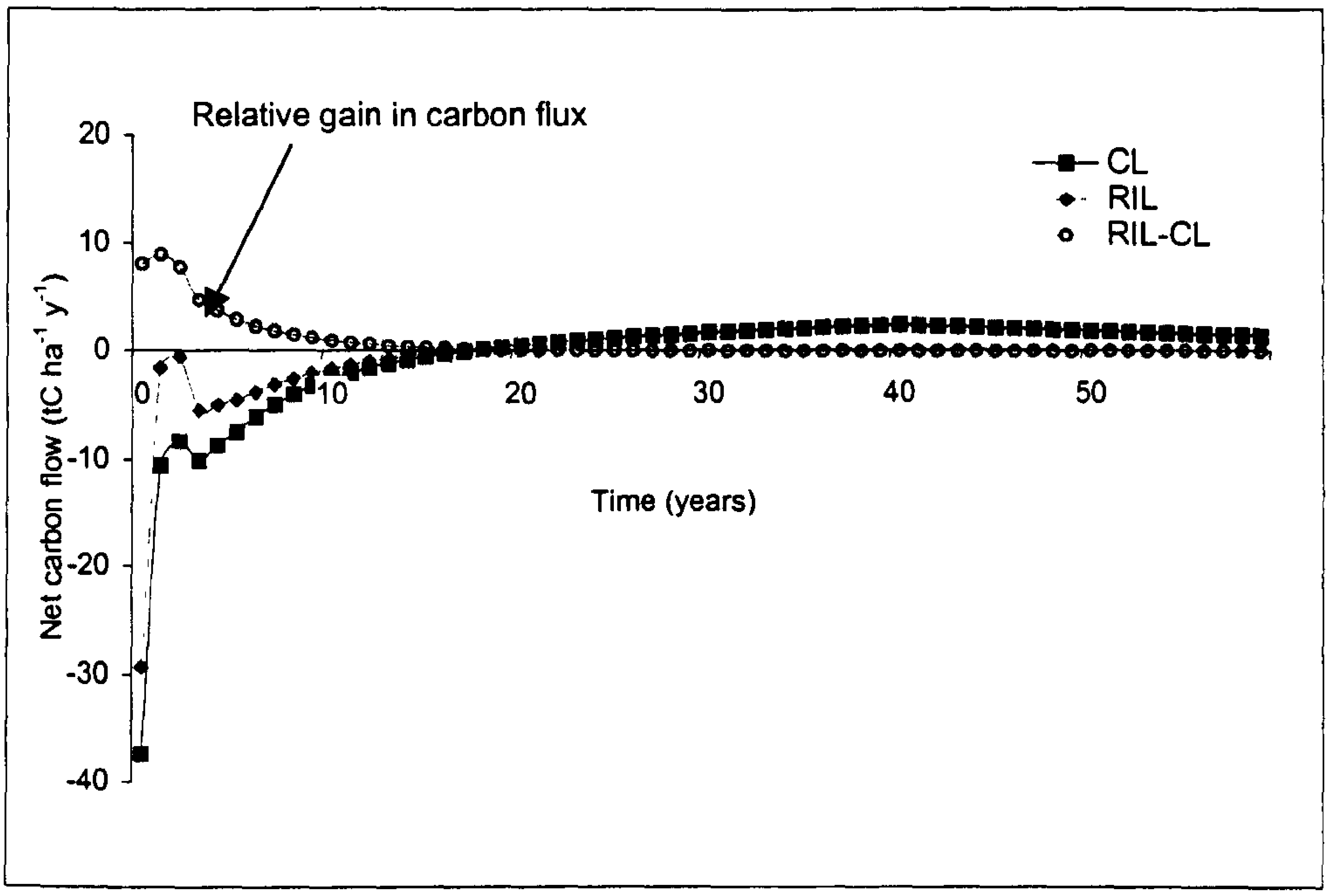


Figure 5.8 Annual net carbon flows (fixation minus emission) due to CL and RIL techniques and net difference between logging techniques (Source of data from Pinard, *unpubl.*)

lower yield and slower working times (chapter 4). However, the per hectare RIL costs have not taken into account of the opportunity costs due to forgone timber.

5.3.5 Cost and benefit analysis

Given that RIL was cheaper per hectare, and stored more carbon, the cost per tonne was negative. At first sight, this might imply a "win-win" situation, but clearly this non-sensible result was due to the exclusion of the opportunity costs of forgone timber harvest in the calculation. The forgone timber harvest was peculiar to RIL, and had a major impact on the carbon economics. It is, therefore, necessary to consider other means of assessing the overall carbon benefit associated with RIL such as including forgone timber, together with non-timber values (e.g. soil or water values), in the valuation. This will be considered in chapter 10. Although it was inappropriate to assign a monetary value to the carbon benefit at this stage, the ultimate carbon cost and benefits analysis in chapter 10 depends on the physical carbon stock or flows in RIL and CL calculated by the FS, MCS and Flow-NPV_{CO_2} methods. The results are presented in the following section.

5.3.5.1 Carbon flows

The non-discounted carbon flows (FS method) in both the RIL and CL units exhibited increasing carbon sequestration benefit (less negative) over the three time periods (Figure 5.9 a). The figures for years 20, 40 and 60 years revealed a closing gap between RIL and CL in the later times. RIL yielded a slight positive flow by year 60.

With discounting, the carbon flows in both the RIL and CL units also showed an increasing trend over the three time periods, but the flow values per period were less than those that were not discounted (Figure 5.9 b). This contrasting result was explicit in the case of RIL units which had negative discounted flow by year 60. At high discount rates, the gap between the RIL and CL units showed little difference because high discount rates put little weight on "late flows". As such the 20, 40 and 60 year figures were similar (Figure 5.9 c and d).

Given the changing flows due to the effect of with and without discounting, this would affect the net carbon flows between RIL and CL. The effect was not significant between no discounting and discounted rates at 2 %. For carbon flows that had been discounted at a higher rates, however, such as at 10 %, the net difference in flows between RIL and CL was nearly half compared with flows that were not discounted (Figure 5.10).

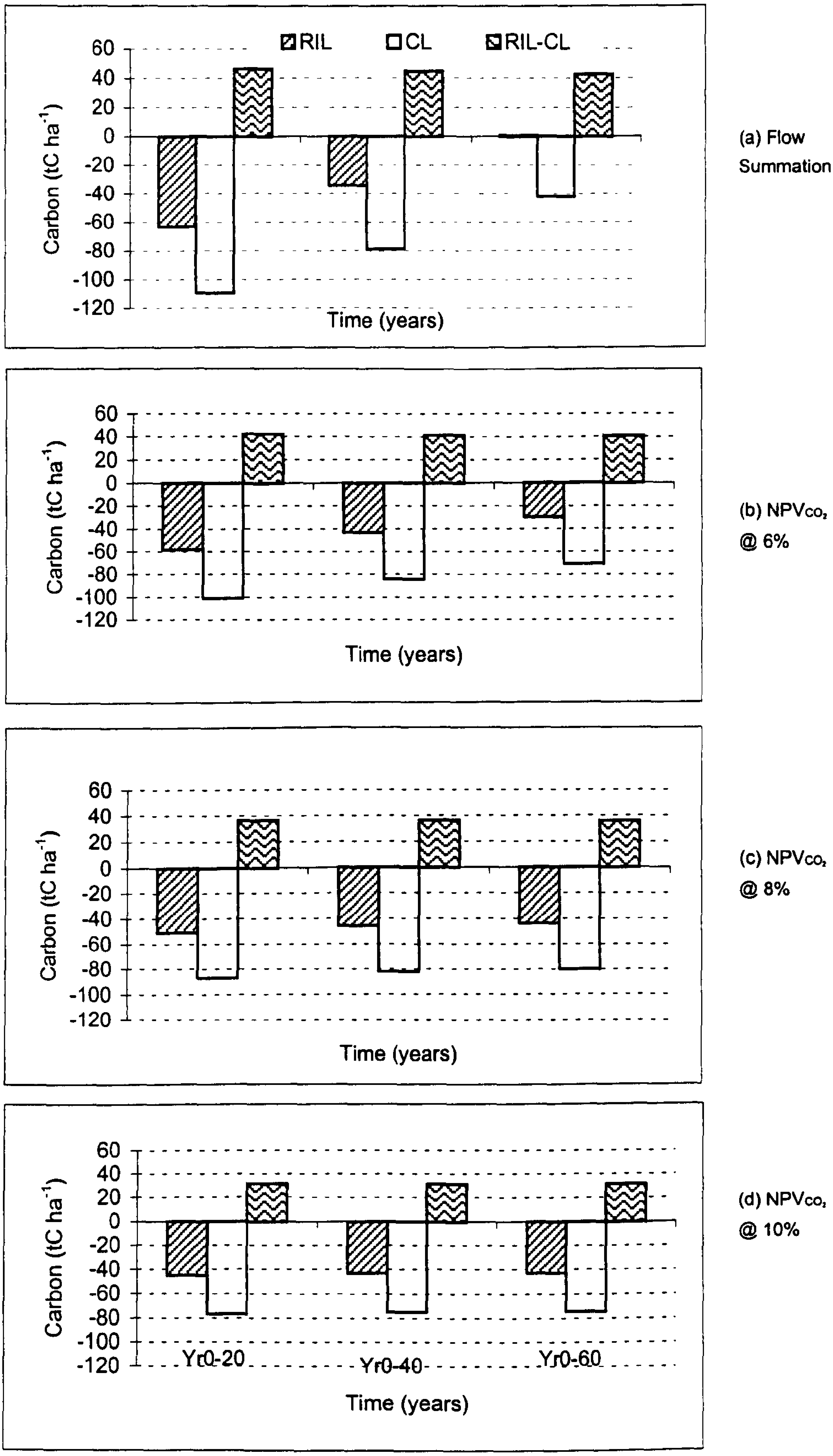


Figure 5.9 The effects of discounting versus no discounting on carbon flows between RIL and CL units over 20-year 40-year and 60-year periods

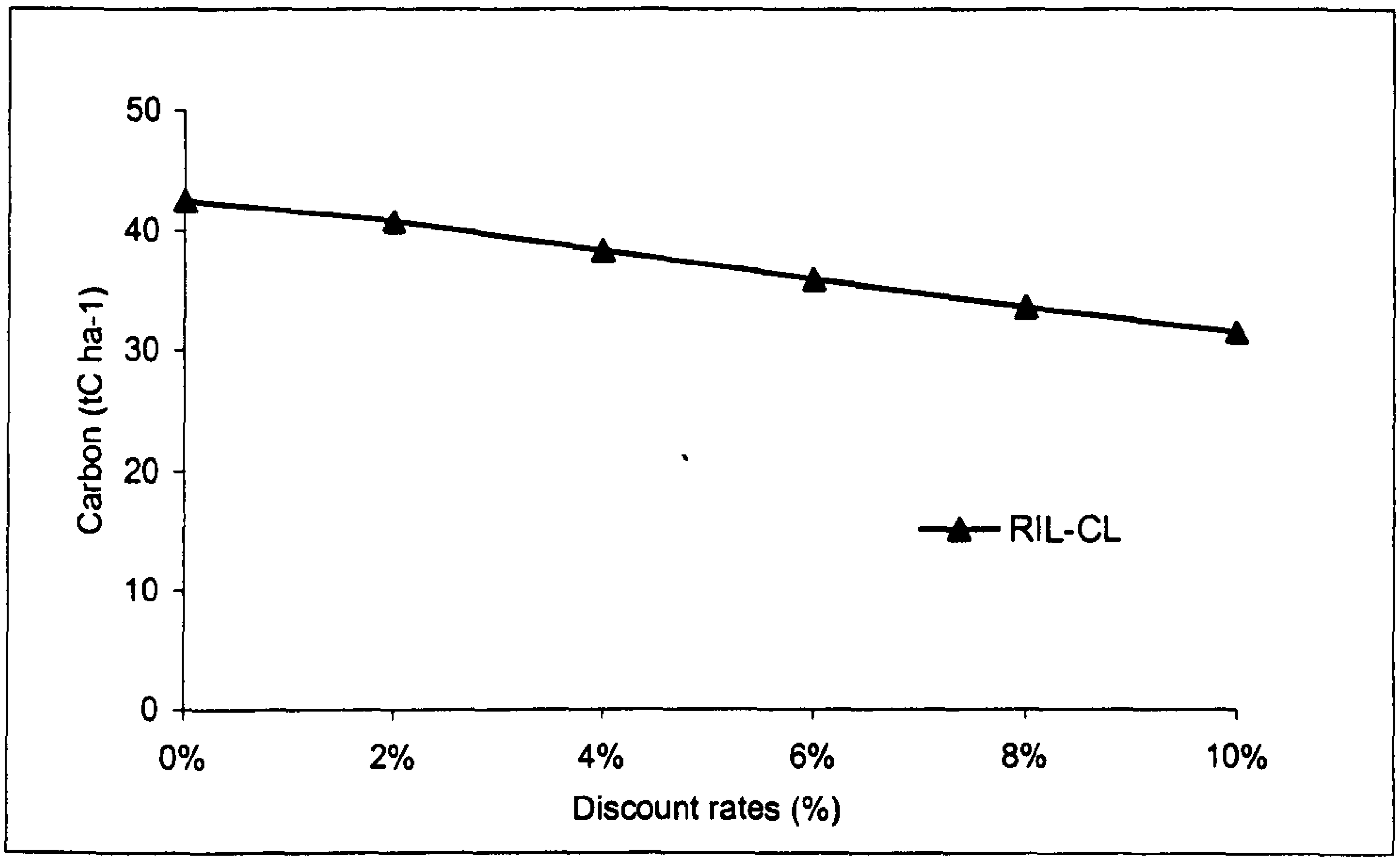


Figure 5.10 Effect of discount rate on net flow between RIL and CL over 60 years crop rotation

5.3.5.2 Mean carbon storage

The mean carbon storage over the three time windows of 20, 40 and 60 years showed a gradual increase in stock over the years for both RIL and CL units (Figure 5.11). The increase was, however, more apparent at the end of year 60. The net difference in stocks between RIL and CL at 20,40 and 60 years were approximately 36, 39 and 40 tC ha^{-1}, respectively.

5.4 Discussion

5.4.1 Forest biomass and carbon

Pre-logging above- and below-ground biomass estimates from the study sites ($mean_{RIL}$=399 Mg ha^{-1}; $mean_{CL}$=394 Mg ha^{-1}) are close to the average for moist forests in southeast Asia (mean=399 Mg ha^{-1}, N=8 stand inventory data sets; Table 5.6) and are within the range of estimates for unlogged forests in Sarawak (280-405 Mg ha^{-1}; Brown *et. al.*, 1991). The below-ground biomass data from this study (67.8 and 67.0 Mg ha^{-1} = 17 % of total biomass) are above the mean of reported values for tropical moist forests (47.4 Mg ha^{-1} =12 % of total biomass), but lie within the range (30.0 – 75.7 Mg ha^{-1}, N=5; Table 5.6). Although the above- and below-ground biomass estimates from this study are near the top of the range of estimates reported in the other studies listed in Table 5.6, they reflect a reasonable estimate. This is because it can be noted from Table 5.6 that major errors are associated with data for below-ground biomass depending on how carefully all roots are extracted for analysis. Therefore, many of the below-ground biomass data are probably major underestimates.

The general pattern of forest biomass (above- and below-ground) storage in the RIL and CL units based on modelling results showed a gradual recovery immediately following logging (starting 8-12 months post-logging), then a drop in storage and a levelling off before recovering at a slow and gradual rate. By year 40, biomass storage in both forests showed a slowing in fixation, and biomass had not reached pre-logging levels at the end of the rotation. The decline in biomass storage during the brief period of post-logging recovery was due to elevated mortality rates due to increased exposure and edge effects (e.g. Whitmore, 1978; Wan Razali, 1989); increased incidence of mechanical damage from vines (Putz, 1991), and competition with pioneer trees and vines (Fox and Chai, 1982). During this period, carbon fixation in new growth was lower than emission rates (due to decomposition of logging debris and necromass) resulting in a negative net carbon balance for as many as 10 years in the RIL units, and 15 years in the CL units. The biomass storage in both RIL and CL units did not reach pre-harvest levels by year 60

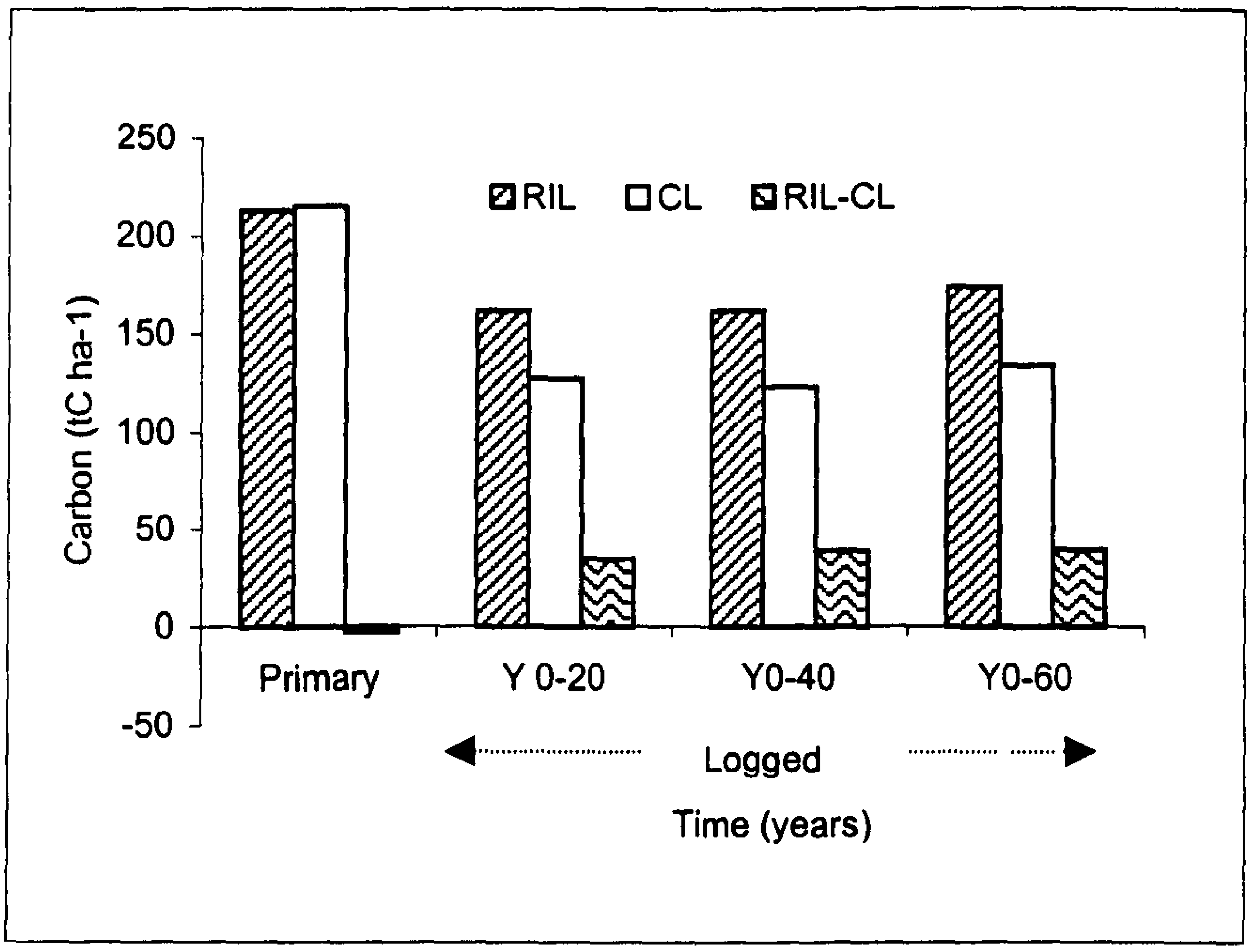


Figure 5.11 Mean carbon storage in the primary, RIL and CL units over over 20-year, 40-year and 60-year periods

Table 5.6 Biomass (dry weight; Mg ha^{-1}) of tropical forest ecosystems

Above ground (AG)			Below ground (BG)		Totals			% of AG+BG		Reference
Stem	Branch	Foliage	Root	Soil	AG	BG	AG+BG	AG	BG	
360.0	-	7.7	32.0	-	367.7	32.0	399.7	92	8	Ogawa, 1982*
286.0	-	8.2	30.0	-	294.2	30.0	324.2	91	9	"
225.4	107.5	6.5	69.2	6.5	339.4	75.7	415.1	82	18	Hozumi, 1982*
197.1	88.1	6.4	49.9	6.5	291.6	56.4	348.0	84	16	"
287.1	59.4	4.8	29.6	13.4	351.3	43.0	394.3	89	11	Bullock, 1981**
522.2	125.4	7.8	-	1.2	655.4	-	655.4	100	-	Kato, 1982*
367.5	90.1	8.0	-	0.2	465.6	-	465.6	100	-	"
346.0	77.0	7.8	-	-	430.8	-	430.8	100	-	"
323.9	91.3	7.2	42.1	5.6	399.5	47.4	429.1			Mean
					399.0	68.0				This study

Source: Nabuurs and Mohren, 1993
* Cannell, 1982
** Reichle, 1981

which was attributed to a decline in growth rates and elevated mortality (Figure 5.7). Although a portion of the carbon held in the decomposing wood may remain on site for several years as soil organic matter (e.g. Johnson *et. al.*, 1991), the increase in soil carbon is expected to be short-lived and total carbon stored in soil is expected to remain fairly stable over time (Johnson, 1993). There are few long-term data against which projections of biomass recovery following logging can be evaluated. The estimates for above-ground biomass at year 60 fall within the range of published values for logged forests in Peninsula Malaysia (Chan, 1982; Brown *et. al.*, 1991).

The main difference between the RIL and CL units in biomass storage and recovery is that the post-harvest decline in biomass in RIL is less severe and of shorter duration. This difference is attributed to RIL techniques which leave a higher and less damaged residual stock of trees. The initial post-harvest difference in biomass persisted to the end of the crop rotation because of two factors. Firstly, the more opened forest in the CL units is favoured by lianes which thrive in the logged-over forest of eastern Sabah (e.g. Pinard and Putz, 1996) and would slow tree growth rates (e.g. Lowe and Walker, 1977) as well as increase mortality rates (e.g. Putz, 1991). This implies that the opened forests (more light) associated with conventional logging might not necessarily increase growth rates of trees. Conversely, the RIL units with their higher stem density, seed trees and less soil disturbance would maintain a better growth throughout the crop rotation. Under these circumstances, it will take a long time before the gap closes. This line of reasoning was supported by the growth modelling results in chapter 4 of this thesis which found that growth rates in the RIL and CL units did not differ significantly for trees greater than 10 cm DBH over 60 years, using *DIPSIM* to model the logged forests (p.m.a.i. for RIL=2.09 m^3 ha^{-1}, CL=1.97 m^3 ha^{-1}; Table 4.16). The second explanation for this gap to persist over the 60 years is associated with the openings occupied by skid trails, log landings, roads where CL units have more extensive openings than those in the RIL units (details given in chapter 6 of this thesis). Growth and yield studies have found that forest recovery in areas scraped and compacted by bulldozers as in these openings is much slower than in areas disturbed by natural treefalls or agricultural practices (e.g. Maycock and Congdon, 1992). Even if left for several hundred years, forest biomass may not fully recover to pre-harvest levels because areas occupied by roads and log landings within the logging coupes may be permanently damaged (Pinard, 1995).

In terms of carbon flow, the projected rate of carbon fixation in both the RIL and CL units was higher than the emission rate after about 11-13 years following logging because of the re-establishment of regeneration in the forest area. During this phase of forest recovery, pioneer trees played a significant role possibly for up to 25 to 30 years (Pinard, 1995). Beyond year 40, carbon fixation rate begins to decline gradually in both the RIL and CL units while rate of carbon emission shows an increasing trend due to elevated mortality of pioneer trees (Pinard,1995, Figure 4.7). The net effect of this is that carbon sequestration benefit in both the RIL and CL units declines towards the end of the 60-year rotation (Figure 5.5).

5.4.2 Carbon flows and stocks

The carbon values that have been presented in this study using the FS, MCS and Flow-NPV$_{CO_2}$ approaches have demonstrated the importance of the carbon profile, the length of the time horizons and the discount rate. The FS and MCS methods ignore the last factor while the Flow-NPV$_{CO_2}$ method embraces all the three factors in the formulation.

The carbon flow profile resulting from the net effect of selective logging (RIL minus CL effects) was characterised by a large sequestration benefit in the initial 10 years and reduces in later years as forests recover from logging. The same profile, however, yielded different totals of carbon using the three approaches for estimating carbon. Over a 60-year period, the FS produced a higher carbon tonne than the Flow-NPV$_{CO_2}$ method as it treated late difference of carbon benefit as equal to early difference.

The time horizon is an important consideration in carbon valuation when discounting is used. The longer the time horizon, the smaller is the distant carbon benefit when converted into present tonnes equivalent (Figure 5.10). This makes the RIL and CL difference smaller because discounting puts less weight on difference of flows, and addresses the relative importance of carbon flows at different points in time (Price, 1997). However, the irregular profile is an argument for using MCS as a basis for calculating the carbon cost.

In relation to the timing of carbon sequestration benefit, the choice of the discount rate has a significant effect on the costing of carbon. As shown in this study, increasing the discount rate from 2 % to 10 % would reduce the carbon benefit from 41 to 32 tC (Figure 5.11). The difference is rather small between RIL and CL techniques but may have greater implication if compared with afforestation options (Price, 1997).

5.4.3 Improvements on carbon estimates

The carbon study can be improved in the following areas as suggested by Pinard (1995):

- Firstly, the biomass expansion factors were based on data taken from Peninsula Malaysia, Indonesia, Cambodia and Brazil. It would improve precision if the biomass expansion factors were generated from the study area

- Secondly, the estimates of necromass produced from logging may not have captured the complete necromass pool even though the sampling was spread over a relatively large area because of problems of below-ground measurement. Furthermore, no effort was made to measure necromass inputs from trees that have been damaged during logging but were not killed (e.g. crowns of snapped off trees, or branches from trees subjected to crown damage) making the estimate conservative. Similarly, trees snapped-off below the crown, which had resprouted at the 8-12 months census, were considered alive although many of these trees will probably die within the second year post-harvest (Putz and Brokaw, 1989).
- Third, fine root biomass was sampled to 10 cm depth which included only 55-60 % of total fine root mass (Green, 1993). The uprooted trees along roads and skid trails used for root biomass estimation may not have complete root systems, and do not represent a random sample from the population. There was also no distinction made between live and dead sections of roots. These factors will affect the accuracy of the root biomass
- The *C-REC* model has several limitations: the most important is that only two ecological groups of species are represented in the model although the diversity of tree species that occurs in the dipterocarp forests of Sabah includes a broad range of tree species exhibiting different architectures, canopy heights, reproductive phenology and physiology. Simulation results are sensitive to small changes in many of these parameters. A more complex model, however, would be difficult to parameterize due to the paucity of data. Similarly, projections of the rate of carbon storage over time involve many assumptions (e.g. growth rates, survival, and wood decay etc), and the uncertainties surrounding these assumptions become greater as the project life-span increases.

5.5 Conclusion

The management objective for RIL techniques in reducing carbon loss (as CO_2) in dipterocarp forest has been met by reducing logging damage by about half compared to forest logged with conventional logging techniques. This resulted in a gain of carbon benefit of approximately 40 tC over 60 years from simulation runs using the *C-REC* model. The variation in carbon values with the three cost-based methods emphasised the importance of the carbon profile or the timing of carbon sequestration, the length of forest rotation and the discount rate in deciding on carbon cost. From an economic perspective, RIL is attractive because it is cheaper per hectare against other forestry options in abating greenhouse gas emissions. However, the opportunity costs of forgone timber harvest associated with RIL have not been considered in the costing, which will have a different economic outcome. This will be dwelt upon in chapter 10.

Chapter 6: Soil

6.1 Introduction

One of the goals of the RIL project in Sabah, Malaysia is to reduce the extent and degree of soil disturbance associated with conventional logging by 50 % (ICSB, 1998). The objective is to increase the capacity of forest as a carbon sink through reduction in unnecessary soil disturbances and openings.

The sources of soil disturbance associated with logging in Sabah can be divided into felling activities and log extraction (Fox, 1968). Falling trees disturb the soil by their impact on the ground. The extent of soil damage caused by felling trees depends on the size of the tree that was felled, and on the degree to which its canopy is linked to other tree canopies by lianes (Appanah and Putz, 1984). This form of soil disturbance is relatively insignificant compared with that incurred in log extraction operations.

Once the tree has been felled and cut into shorter lengths, it must be hauled away from the felling site to the log yard for further processing. The transfer of a log from stump to log yard is facilitated by the construction of a network of skid trails and roads throughout the forest as well as log landings for temporary log storage, debarking and numbering prior to being hauled out by trucks. The bark of trees is left at the fringes of log landings which could be used for soil restoration when logging is completed.

Each log landing ranges from 0.1 to 0.5 ha and up to 1-3 landings are created per logging unit of 100-200 ha. The bulldozers used to construct skid trails, log landings and roads (hereafter openings) are the Caterpillar D7 which are very powerful machines (215 hp) equipped with a heavy-duty front blade that can easily push over vegetation and the soil along their path. The top and sub-soil that has been pushed over main skid trails, roads, and log landings will smother seedlings along the edges of these openings, and form mounds that later becomes sites for vegetation to re-establish (Pinard *et. al.*, 1996).

The same powerful Caterpillar D7 is also utilised for extracting logs from the stump to the log landing along a skid trail which has been made by the use of the blade. In wet weather and on undulating ground, more frequent blade work is necessary to obtain traction over repeated passes along main skid trails. Consequently, soil disturbance on the surface of main skid trails and log landings is much more severe and has far more implications. The loss of a protective layer of leaves, litter and roots and herbaceous cover on exposed soils accelerates soil losses during rainstorms in the forms of erosion. Gullying and mass movements also on skid trails and roads as skid trails cross water-courses without any drainage; and roads (for wheeled vehicles) involve the additional construction (and disturbance) of drains and bridges. All of these acts as important focal points of high rates of soil erosion and have a very high impact on sedimentation in water course. This has adverse effects on on-site as well as off-site productivity (Bruijnzeel and Critchley, 1994).

Often, repeated use of heavy machinery on the exposed soils changes the soil physical properties in ways that hinder forest recovery e.g. the recruitment of pioneer trees after logging (Pinard *et. al.,* 1996). A study in eastern Sabah revealed that compacted skid trails and log landings have a higher bulk density, lower moisture content, and lower organic carbon, nitrogen, phosphorus compared with forest soils; consequently inhibiting growth of tree seedlings (Nussbaum *et. al.*, 1995; Pinard *et. al.*, 1996). Compaction also caused poor infiltration rates, e.g., a study in western Sabah reported that log landings have infiltration rates as low as 0.58 mm hr^{-1} compared with 154 mm hr^{-1} in undisturbed forest (Malmer and Grip, 1990). Poor infiltration in turn increases overland flows during storm events and accelerates soil loss as well as washing away seeds falling on the openings (Pinard, 1995). However, the degree of soil disturbance depends on a combination of factors as follows:

(a) Skid trail, log landings and roads

- soil, geology and topography (Gilmour, 1982; Douglas *et al.,* 1990);
- logging timing with respect to wet and dry season and individual rain events (Queensland Forest Service, 1991);
- extent, nature, and usage of skid trails, log landings and roads particularly their orientation with slope; length of down slope run, and position on slope with reference to watercourses (Kamaruzaman and Nik, 1986; Malmer, 1990; Philips, 1986; Baharuddin, 1992; Nussbaum *et al.,* 1995);
- the promptness with which regeneration occurs (Rusland and Manan, 1980; Nussbaum *et al.,* 1995; Pinard *et. al.*, 1996);

(b) Extraction activities

- amount of vegetation cover removed (Abdul Rahim and Harding, 1993);
- amount of slash remains on the area (Hamilton and King, 1983);
- extraction method and the way it is implemented (Malmer and Grip, 1990);
- presence or absence of adequate riparian buffer strips (Sabah Forestry Department, 1974; Queensland Forest Service, 1991);
- nature of climatic events following disturbance (Rusland and Manan, 1980)
- size of trees removed (Pinard, 1996; Verissimo *et. al.*, 1995)

One of the main concerns about soil disturbance associated with logging is that it adversely affects forest recovery. Severely disturbed areas, such as log landings and roads, take many years before trees recover from logging or they may not ever recover in many instances (Malmer and Grip, 1990; Uhl *et. al.*, 1982). There are many factors which contribute to arrest forest recovery via succession. For example, the absence of mother trees (Pinard *et. al.*, 1995); soil compaction and its inhibition of root growth (Van der Weert, 1974; Pinard *et. al.*, 1996); reduced infiltration creating water stress (Awang and Sawal, 1986); low soil fertility (Pinard *et. al.*, 1996), seed desiccation due to increased insolation following logging (Sasaki and Mori, 1981); high soil temperatures that kill mycorrhizas necessary for initial plant growth (Lee *et. al.*, 1996); and increased herbivory by mammals and insects on seeds and seedlings (Becker 1985). Slow recovery of forest following logging in openings means the productive area of the forest is reduced in the next harvest. With skid trails and landings representing up to 40 % of the logged area following conventional logging, the economic consequences of slow forest recovery are drastic (Nicholson, 1979; Jusoff, 1991)

Given the many environmental imperatives of forest recovery following logging, one could do the following to mitigate the impacts of logging on soil damage:

(i) reduce the area for skid trails, log landings and road;
(ii) reduce the impact by positioning/orientating to mitigate soil erosion;
(iii) reduce their impact by how they are used;
(iv) restore them afterwards.

The most immediate and cost-effective soil conservation option is to reduce the extent of the openings occupied by skid trails, log landings and roads (Fox, 1968; Liew, 1973). Studies have shown that it is possible to reduce these openings by more than half using improved logging operations (Nicholson, 1979; Hendrison, 1990). Based on preliminary findings, the RIL project has obtained similar success using the harvesting guidelines as highlighted in the following points (details are given in Table 3.1 of Chapter 3 (Marsh *et. al.*, 1994)):

- *skid trails*: width is restricted to 4.5 m on gradients up to 20° and 5 m on gradients over 20°; side-cutting is not allowed on slopes >20°; blading is not allowed on slopes >15° but with care on slopes <15°; water bars must be installed post-harvest to drain runoff; no skid trails are allowed on slopes >35°; prohibition of skidding in rain
- *log landings*: where possible, all log landing operations should be conducted on existing roads; dimensions of landings should not exceed 0.18 ha; density of landings shall not be more than 3 units per 40 ha of harvested area

- *roads*: earth movements should be minimised during construction of roads; felling of trees to allow more sunlight to dry the soil should be confined to wet stretches only

These guidelines differ from conventional logging in many respects. There are no restrictions on width of skid trails in conventional logging except through the 'common' sense of the bulldozer operators. Blading of soil is used whenever 'necessary' and on any slopes. The size of landings can be up to 0.5 ha, particularly on flatter ground and there is no restriction on the number of landings per unit area appealing again to 'common' sense. In many instances, felling of trees along roads to dry them is excessive and unnecessary.

It also makes economic sense to minimise unnecessary openings associated with logging because it is costly to reforest and rehabilitate these areas. It costs approximately RM50 to RM250 ha^{-1} to rehabilitate degraded areas and the recurring administration and management cost is between RM1.25 to RM3.75 ha^{-1} annually (Leslie, 1987). In Sabah the cost of rehabilitating seven hectares of log landings with mixed indigenous species at a 2 m x 1 m spacing was estimated to be a much higher figure of RM2,750 ha^{-1} (Nussbaum *et. al.*, 1996).

Evaluating soil conservation benefit based on the area of production forest forgone is rarely done. By most accounts, cost-benefit analysis of soil conservation schemes is mainly on re-engineering practices to stabilise soil erosion, gully erosion, and mass soil movement (Gregerson *et. al.*, 1987). For example, the costs are estimated of: use of gully control structures to stop erosion; construction of slope stabilisation structures; re-vegetation and management of vegetation to protect soil; construction of sediment basins; forest protection and management etc. While the approach to evaluating soil conservation schemes differs, the need to present its benefit in economic terms is unambiguous, and is an important one, to highlight the importance of reducing soil disturbance associated with logging.

The aim of this chapter is to examine the economic costs of the loss of forest (timber) productive capacity due to soil damage on skid trails, road and landings. It measures this loss in terms of the potential value of the timber on these openings. This chapter is headed soil because it deals with the value of soil in situ for the production of timber. The economic consequences of soil damage are featured centrally in chapter 5 and chapter 8. Chapter 5 accounts for the differential rate of biomass and carbon recovery on skid trails which implicitly looks at the soil recovery rates. The economic consequences of soil erosion are dealt with in chapter 8.

To quantify the extent and degree of disturbance on the skid trails, road and log landings, a field inventory in the experimental area was conducted. The field inventory was developed and executed jointly by Dr Michelle Pinard and myself assisted by a team of seven crews. To explore how soil recovered on skid trails following logging, skid trails of 1, 6 and 18 years old were inspected by me and these observations related to research carried out by other workers within the Ulu Segama Forest Reserve (e.g. Nussbaum, 1995, Pinard *et. al.*, 1996). Based on the results, the following are discussed: different ways of economically analysing the impact of soil loss; the benefit of reduced soil disturbance; implications for the relationship between type or degree of soil damage and recovery of vegetation; and management options regarding future uses of these areas.

6.2 Methods

6.2.1 Estimating the extent of skid trails, log landings and roads

For the purpose of estimating the extent of openings occupied by skid trails, log landings and roads in the experimental area, we measured their length and width using tapes and compasses to record the bearings in each of the eight logging units that had been established for monitoring the overall impacts of logging between RIL and CL techniques. The widths of skid trails and roads were measured at intervals of 10-15 m along their length. Soil disturbance along skid trails was categorised into three types as follows:

- *bladed* soil refers to surfaces with top soil completely removed exposing the sub-soil. This type of soil condition are commonly found on skid trails that are used as the 'main' trail serving other 'secondary' trails. Skid trail with bladed soil is considered 'bad' as it is devoid of ground cover and has soil conditions not conducive to tree regeneration;
- *churned* soil refers to a mixture of top and sub-soils. This type of soil disturbance is found on skid trails that are used for not more than three bulldozer passes to access fallen trees. There is a good chance that trees will re-generate on churned soil because the top soil is still present to provide the necessary nutrients (e.g. via mycorrhiza) for seedlings to establish;
- *intact* soil refers to openings with top soil still intact but having been traversed by a bulldozer. This is the most preferred type of disturbance on skid trails because trees will regenerate quickly under such condition of disturbance considered as light disturbance.

The extent of soil that had been pushed to the sides of skid trails (side-cast) was measured at intervals of 10-15 m along its length. For irregular shaped side-casts, the average maximum and minimum distance at each specified interval was taken.

6.2.2 Estimating soil recovery on skid trails, log landings and road

Soil recovery is a complex process and depends on several factors, e.g.

- the presence of trees on or at the edges of skid trails; the height of shrubs or trees influencing splash erosion from rain drops;
- state of the soil (compaction, fertility etc); the input of litter above- and below-ground: factors affecting the rate of litter decay and nutrient mineralisation, such as the moisture content and temperature of the soil influenced by the amount of incident light;
- depending on the soil structure; degree of soil compaction; presence of roots and fauna in the soil; litter layer on the soil surface; number of leaf layers in the canopy, (if ground vegetation grows up densely so that all leaf layers are a long way above the ground then this could lead to erosion problems if the soil surface is bare);
- There is also a potential conflict between conditions that favour rampant growth of ground cover which leads to good soil protection, and the effect of that ground cover preventing the regeneration of timber tree species.

The results of the interaction of the above list of factors on soil recovery can vary from months to decades beyond the time frame of this study (Pinard, *pers. comm.*). Given the lack of information on the above, the alternative approach undertaken in this study to evaluate soil recovery on the openings was to inspect several one-year-old skid trails in RIL units, and skid trails of one, six and 18 years old in CL units, and relate their degree of soil stability to a qualitative assessment of the amount of re-growth (vegetative cover) and litter-cover post-logging. The field observations were compared with published work on tree regeneration on abandoned log landings and skid trails based on two research projects conducted by Pinard and Putz (1994) and Pinard *et. al.* (1996). The earlier work of Pinard (1994) was on the limiting factors on the establishment of pioneer species on log landings and skid trails. In the later work of Pinard *et. al.* (1996), the study examined tree recovery in logged-over forests of different ages (1991, 1988 and 1976).

6.2.3 Basis of evaluating benefit forgone on skid trail and log landings

Preliminary field observations of logging operations in the study area revealed that the RIL units generally have a smaller area of skid trails, log landings and roads compared with CL units (Marsh *et. al.*, 1994). On this basis, the areal difference of these openings between the CL and RIL units represents the area lost to future forest production in CL units. Conversely, any reduction in openings compared with CL would represent a benefit of RIL because of the area of land that remains as productive forest (carrying valuable timber during the next cut) rather than being converted to skid trail and log landings.

The basis of evaluating the benefit due to RIL was in terms of the potential value of timber forgone for the CL units at the second harvest (year 60). It is not relevant to consider the difference in the value of the timber at first harvest on skid trails and log landings between RIL and CL because all of that timber was logged during the first harvest (year 0) and is accounted for in chapter 4.

For the t_{60} valuation of benefit forgone on skid trail and log landings, the implicit assumption being made is that the same logging methods will be used in each unit of forest at each rotation, and therefore that the same skid trails and landing sites will be used, i.e. these extraction areas are being taken permanently out of timber production. As such, the forest growth simulation in chapter 4 excludes those plots that contain skid trails and roads. Therefore, there is no double accounting of the timber benefit between chapters 4 and 6 of the year 60 value of the timber in the difference in extraction area.

6.2.4 Evaluation

The benefits of reducing openings were evaluated based on the value of timber forgone in the second cut at year 60. The calculation of the timber value in the RIL and CL units involves revenue and cost determination, which has been presented in Chapter 4. The reduction of net benefits due to additional openings of skid trails and log landings in the CL units was calculated by taking the difference of the two sets of estimates obtained for RIL and CL units. The net present value between RIL and CL was estimated at discount rates of 2, 4, 6, 8 and 10 %. The intention of having a range of discount rates is to allow decision-makers to choose their discount rates in discussing policy issues.

6.3 Results

6.3.1 Impacts of logging on skid trails, log landings and roads

The total area of skid trails, log landings and roads in the RIL units was only 40 % that in CL units ($mean_{nl}$=9.3 ha ± 0.3SE; $mean_{CL}$=29.2 ha ± 0.4SE; Table 6.1). They represented approximately 7 % and 17 % of the total area logged in the RIL (129 ha) and CL units (175 ha), respectively. All three categories of openings (skid trails, log landings and roads) in RIL units were smaller than in CL units but only skid trails showed significant difference in area between the treatments (Table 6.1).

Table 6.1 Area occupied by skid trails, log landings and roads in RIL (129 ha) and CL (175 ha) units

	Conventional Logging (CL)				Reduced Impact Logging (RIL)				t-test
Logging reference number	*23*	*38*	*39*	*41*	*30*	*36*	*35*	*32*	
Area logged (ha)	41.5	37.1	50.0	46.4	36.9	23.0	44.3	24.6	
a) By absolute area (ha)									
Skid trails	4.0	4.2	5.5	7.3	0.9	0.5	1.3	1.6	
Log landings	0.4	0.2	0.2	0.9	0.0	0.0	0.5	0.2	
Roads	1.6	1.3	2.6	1.0	1.3	0.3	2.7	0.1	
Total	5.9	5.8	8.3	9.2	2.2	0.8	4.4	1.9	
	Total	Mean	±SE		Total	Mean	±SE		
Skid trails	21.0	5.3	0.8		4.3	1.1	0.2		(t=6.685,P=0.007)**
Log landings	1.7	0.4	0.2		0.7	0.2	0.1		(t=0.875,P=0.446)
Roads	6.5	1.6	0.4		4.3	1.1	0.6		(t=0.618,P=0.579)
Total	29.2	7.3	0.5		9.3	2.3	0.8		(t=2.446,P=0.0048)*
a) By proportion of total area logged (%)									
Skid trails	9.68	11.35	10.90	15.80	2.50	2.09	2.85	6.46	
Log landings	0.89	0.62	0.46	1.88	0.00	0.00	1.04	0.85	
Roads	3.76	3.58	5.22	2.09	3.39	1.26	6.14	0.30	
Total	14.33	15.56	16.58	19.77	5.89	3.35	10.03	7.62	
	Total	Mean	±SE		Total	Mean	±SE		
Skid	12.01	11.93	1.34		3.30	3.48	1.01		
Log landings	0.97	0.96	0.32		0.52	0.47	0.28		
Road	3.70	3.66	0.64		3.37	2.77	1.29		
Total	16.67	6.45	1.16		7.19	1.97	1.41		

** $P < 0.01$ * $P < 0.05$

RIL units had a smaller area of skid trails occupying 4 % of the total area logged compared with 12 % in CL units (Table 6.1). Skid trails in CL units, however, ramified through a far larger proportion of the total forest area (Figure 6.1). The average length per kilometre of skid trails in the RIL units was significantly shorter compared with those in the CL units ($mean_{RIL}$ = 2.04 ± 0.37 m; $mean_{CL}$ = 8.71 ± 0.99 m; Table 6.2) but skid trail widths were the same in both experimental units.

Skid trails in the RIL units with a bladed surface (see definition in section 6.2.1 this chapter) were only half the proportion encountered in the CL units ($mean_{RIL}$ = 38 % ± 5.0 SE; $mean_{CL}$ = 87 % ± 2.8 SE). The proportion of skid trail area with churned soil in the RIL units was higher than in the CL units ($mean_{RIL}$ = 50 % ± 3.6 SE; $mean_{CL}$ = 11 % ± 2.6 SE). The proportion of skid trail area with intact topsoil was also higher in RIL units than in CL units ($mean_{RIL}$ = 12 %; $mean_{CL}$ = 2 %).

The average size of log landing in the RIL unit was less than half that in the CL units ($mean_{RIL}$ = 0.7 ha; $mean_{CL}$ = 1.7 ha, t=1.388, *P*=0.259). However, log landings occupied less than 1 % of the total area logged in both experimental units.

The total area of roads in RIL units was slightly more than half that in the CL units ($mean_{RIL}$ = 4.3 ha; $mean_{CL}$ = 6.5 ha). Roads represent approximately the same proportion in both RIL and CL units; about 4 % of the total area logged.

6.3.2 Soil recovery on log landings and skid trails

In the RIL units, one-year-old skid trails had re-growth that reached closed-canopy at height of 4-7 m (*pers. obs.*). Pioneer trees (*Macaranga* spp. and *Anthocephalus* spp.) were most abundant. Other vegetation included *Chromolaena odorata, Imperata* spp., sedges, Zingiberaceae plants and vines with *Uncaria* spp. most common. Both Dipterocarp and pioneer species seedlings were found along the skid trails.

In the CL units, ground cover of the one-year-old skid trails consisted mainly of herbaceous and/or shrubby woody species such as *Merrimia* spp., Zingiberaceae, and grasses of the *Imperata* spp. On the 6 and 18-year-old skid trails, soil erosion appears to have become reduced to a low level: the soil surface was covered with a dense litter layer. The skid trails also had a dense cover of plant regeneration (about 90 %) mostly of *Imperata* spp., *Chromolaena* spp., sedges and some tree species (approximately 5 % of the area). Most overtopping shade over the six-year-old skid trails was provided by overgrown shrubs and lianes to 5 m tall. Conversely, the canopy layer was higher in the 18-year-old stand comprising the tree species *Octomeles* and *Anthecephalus* at 35-45 cm

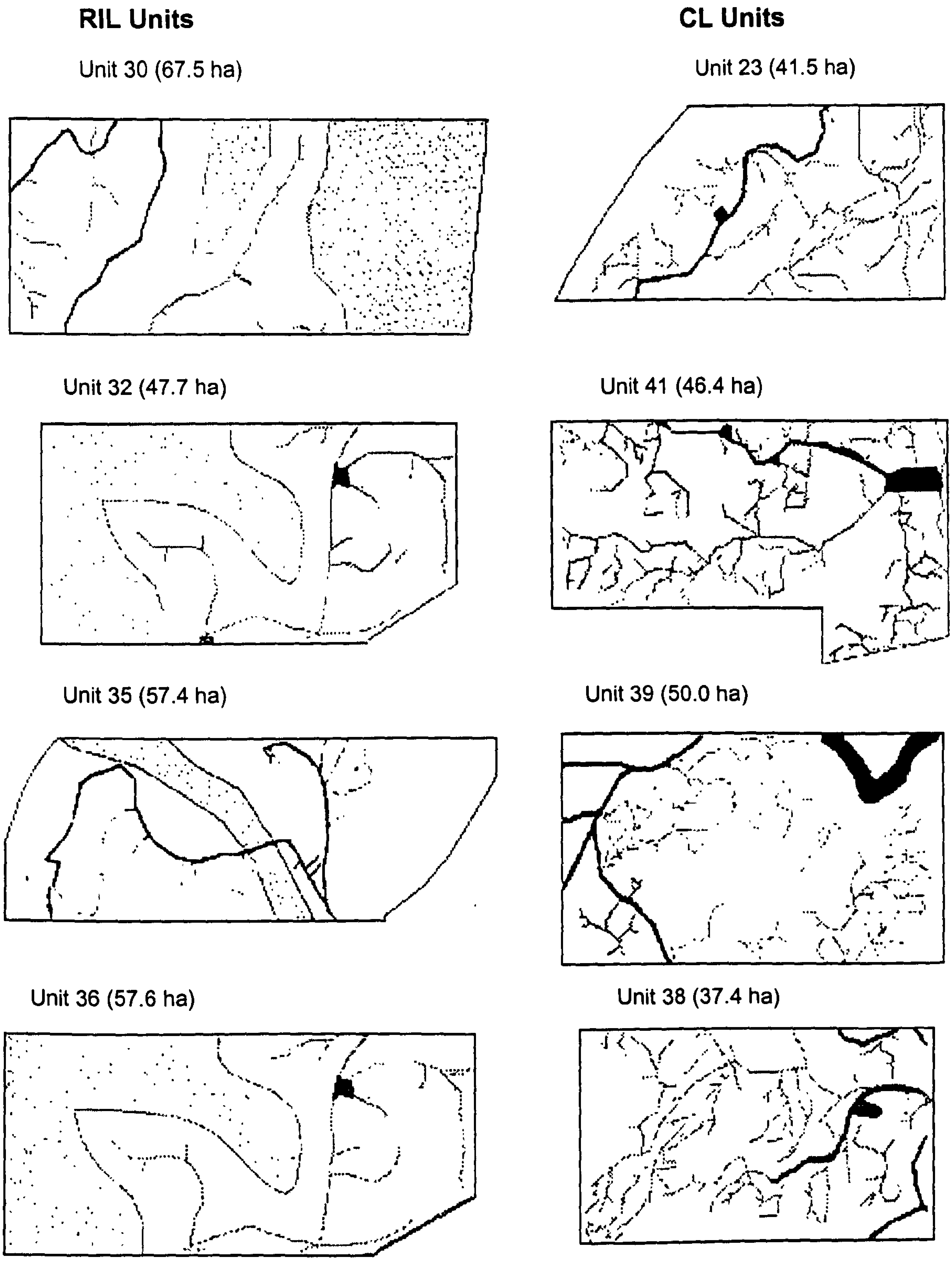


Figure 6.1 Extent and intensity of skid trails (light line), log landings (dark lumps) and roads (dark lines) in CL and RIL units. The shaded areas in the RIL units represents unlogged areas, where slope is greater than 35°.

Table 6.2 Skid trail and road characteristics in the CL and RIL logging units

		Conventional Logging (CL)				Reduced Impact Logging (RIL)				t-test
a) Total length and mean width										
Logging reference number		*23*	*38*	*39*	*41*	*30*	*36*	*35*	*32*	
Skid trails	*Length (km)*	6.59	7.84	9.18	11.22	2.18	0.98	2.65	2.36	
	Width (m)	6.10	5.37	5.94	6.53	4.23	4.90	4.76	6.73	
Roads	*Length (km)*	0.84	0.98	1.43	1.42	1.02	0.20	2.41	0.13	
		Total	Mean	±SE		Total	Mean	±SE		
Skid trails	*Length (km)*	34.83	8.71	0.99		8.17	2.04	0.37		(t=6.684, P=0.007)**
	Width (m)		5.99	0.24			5.16	0.54		(t=0.674, P=0.549)
Roads	*Length (km)*	4.67	1.17	0.15		3.76	0.94	0.53		(t=0.476, P=0.681)
b) Type of disturbance										
Skid trail disturbance (%)										
	Bladed	93	80	90	85	39	27	51	34	
	Churned	5	17	9	13	57	56	45	43	
	Intact	2	3	1	2	4	23	4	3	
			Mean	±SE		Total	Mean	±SE		
	Bladed		87.00	2.86			37.75	5.06		(t=6.199, P=0.008)**
	Churned		11.00	2.58			50.25	3.64		(t=7.519, P=0 005)**
	Intact		2.00	0.41			8.50	4.84		(t=1.225, P=0.345)

** P < 0.01 * P < 0.05

DBH along the edges of the skid tails. Dipterocarp seedlings were found in scattered places along the skid trails with heights of up to 15 cm (no estimate was made on the density of seedlings on skid trails).

6.3.3 Cost of timber forgone

The profits from timber benefit for the RIL and CL units have been estimated to be RM24,701 and RM24,554 ha^{-1}, respectively (chapter 4, Table 4.25). Based on these profit margins, the potential value of timber on the 9.3 ha representing area of log landings, skid trails and road out of the 129 ha that was logged in RIL amounted to RM229,719 equivalent to RM1,7811 ha^{-1} (Table 6.3).

For the CL units, the potential value of timber on these openings was much higher with an estimated value of RM716,977 or RM4,097 ha^{-1} for an area of 29.2 ha out of the logged area of 175 ha.

The per hectare net difference in value between RIL and CL amounted to RM2,316. This amount represents the lost in productive land for the second cut and the next successive cuts in the CL units.

If the value of this loss of productive land was discounted at 2 %, the net present value for RIL and CL would be reduced by three times compared with no discounting (RIL = RM70,064, CL = RM218,678). The per hectare values for RIL and CL were RM1,250 and RM543, respectively. At a higher discount rate of 10 %, the net present value for RIL and CL units would be reduced by 333 times to RM5.34 and RM12.29 ha^{-1} , respectively.

6.4 Discussion

The primary aim of this chapter is to evaluate the value of soil in situ for the production of timber. It does this solely based on the total proportion of the area of RIL and CL units initially converted to skid trails, landing sites and roads. It assumed that the same logging techniques will be used in each unit of forest at each rotation, and therefore that the same skid trails and landing sites will be used, i.e. these extraction areas are being taken permanently out of timber production.

The results showed that by using RIL techniques to harvest timber, the extent of skid trails, log landings and roads in the RIL units was reduced by nearly 60 % compared with CL units. Skid trails and log landings, in fact, accounted for 90% of this reduction in total openings. The difference in the area of skid trails and log landings between RIL and CL units may be due to the fact that bulldozers did not traverse slopes greater than 35° in

Table 6.3 Economic values for loss of timber on roads, log landings and skid trails in CL and RIL units

Particulars		CL	RIL	RIL-CL
A. Openings (ha)				
1 Roads		6.5	4.3	
2 Log landings		1.7	0.7	
3 Skid trails		21.0	4.3	
Total		29.2	9.3	
B. Financial (RM ha^{-1})*				
1 Timber revenue		55,133.00	73,260.00	18,127.00
2 Harvesting cost		30,579.00	48,559.00	17,980.00
Net (Revenue - cost)		24,554.00	24,701.00	147.00
C. Revenue forgone in openings **				
1 No discounting	0%	716,976.80	229,719.30	
2 Discounted at	2%	218,677.92	70,064.39	
	4%	68,112.80	21,823.33	
	6%	21,509.30	6,891.58	
	8%	7,169.77	2,297.19	
	10%	2,150.93	689.16	
D. Revenue forgone per hectare ***				
1 No discounting	0%	4,097.01	1,780.77	2,316.24
2 Discounted at	2%	1,249.59	543.13	706.45
	4%	389.22	169.17	220.04
	6%	122.91	53.42	69.49
	8%	40.97	17.81	23.16
	10%	12.29	5.34	6.95

Note: * Represents timber benefit forgone: the data are from chapter 4 (Table 4.25)
** Calculation: Total in item A multiplied by net revenue in item B for non-discounting. Discounted revenue is formulated by $1/(1 + i)^{60}$ where i is the interest rate
*** Item (C) divided by total area logged in RIL and CL (RIL = 129 ha; CL = 175 ha)

RIL areas, so may have limited the extent of skid trails and log landings. Another factor is that in the RIL units, roadsides were used as log landing sites for temporary holding of logs unless it is necessary to clear land for this purpose. The size of log landing was kept below 0.18 ha per unit. The RIL harvesting specifications have no effect on the roads in the two experimental units because roads were constructed within the RIL and CL units before adoption of the RIL guidelines

The proportion of openings in the RIL units (7 %) was comparable to findings in Australia (5 %, Crome *et. al.*, 1992) but was less than half when compared with most other studies of supervised logging. For example, one study in Suriname reported supervised logging resulted in 16 % of openings against the total logging area (Hendrison, 1990) whereas in Brazil was 20 % of total area logged (Johns *et. al.*, 1996). In Sarawak Malaysia, it was reported that openings occupied about 20 % (Marn and Jonkers, 1982). There are three possible explanations for the much lower estimate obtained in this study compared with higher estimates found in Suriname, Brazil and Malaysia. Firstly, the location of the present study area was on hilly terrain which did not give the bulldozer operator much chance to create openings for skid trails or landing sites. Secondly, the RIL guidelines on skid trail access, landing size and no logging zones are possibly stricter than other harvesting guidelines which resulted in the much lower extent of openings in the RIL units. Thirdly, the difference among studies could be due to differences in sampling methods or biases (e.g. towards roadside locations): this study is relatively free from sampling biases because soil disturbance associated with logging was measured in 100 % of the area of the eight logging units.

In contrast with the results reported for RIL units, the proportion of openings in the CL units (17 %) was representative and comparable with published values for unsupervised logging in Malaysia (17 % by Borhan *et. al,* (1987); 16 % by Jusoff and Nik (1992)); and was similar to values for operations in Suriname (14.5 % and 16 %, Hendrison (1990) and Indonesia (16 %, Cannon *et. al.*, 1994). One particular exception is Fox's (1968) work in Sabah who reported a much higher figure of 43 % for openings. This figure is twice the extent compared with CL techniques in this study as well as the others. Three explanations could be given for the higher estimate in Fox's study apart from differences in sampling method or biases. Firstly, the work site may be situated on an undulating terrain in which case, there is a tendency for bulldozer operators to 'roam' about the forest, and built excessively large log landings to make it easier for the loading of logs onto trucks. Secondly, it could be due to a far higher proportion of the timber volume being harvested in that study. Thirdly, it could be due to the absence of a set of harvesting guidelines restricting the construction and use of skid trails as well as the use and location of landing sites; compounded by poor supervision in the field that led to a 'free-style' logging.

When the additional openings created in the CL units are monetized in terms of the potential value of timber that would be forgone in the second harvest at year 60, this amounted to RM2,316 ha^{-1} for the difference in open areas between RIL and CL units. If discounted at 2 %, the amount would be RM766 ha^{-1}. However, this potential benefit of using RIL to harvest timber is based on two key assumptions: firstly, the openings created in the first harvest will be re-used for future entry; secondly, the time taken for forest to recover in the openings within RIL and CL units did not differ, i.e. there was no difference in the degree of soil disturbance in the RIL and CL units.

The first assumption is deemed the likely outcome for this study area given that there is a need to get access to the forest for intermediate surveys or inventories during the felling rotation. There is, therefore, a need to keep roads open and bridges maintained to enable access. It is also likely that log landings that have been created in the CL units will not recover fast enough for the second harvest, because most of the top soils had been removed and compacted with the repeated passes made by heavy machines, and so had made it unsuitable for growth (Nussbaum *et. al.,* 1994).

If indeed the soils in the skid trails did recover, this will have a different economic implication. The potential economic implications of the greater rate of soil/forest recovery on skid trails and log landings in RIL forest would be relevant (a) if the smaller diameter wood growing on skid trails could be harvested and converted into lesser value products (e.g. pulp-wood or fuel-wood before the trails were reopened at the next harvest; or (b) if both RIL and CL forest was logged by RIL at the second harvest and subsequent rotations. In (a), however, the soil recovery rate may be sufficiently slow that no trees regrowing on the RIL skid trails or landings are likely to reach harvestable size (greater than 60 cm DBH) by year 60. If they reach a much larger size than trees on the CL skid trails by that time, this land would have more value, e.g. if the RIL skid trail trees had exceeded 30 cm DBH by year 60, and the CL trees had not, then these areas could be harvested at the end of the second rotation in RIL, but not in CL.

Field observations of plant regeneration on RIL's skid trails indicate some encouraging signs and revealed that as well as the RIL plots having lower total area of openings in the RIL units, the soil in the openings in the RIL units is less severely damaged than in the CL units. The degree of soil disturbance indicated by the proportion of bladed surface (top soil removed) on skid trails in the RIL units was only half of that in the CL units. The need to blade soil is inevitable in tropical logging condition especially during wet weather skidding because the bulldozer has to have ground traction to extract logs over repeated passes. A higher proportion of bladed surface implies a higher degree of displaced soil with adverse on-site and off-site externalities. This usually occurs in areas with slopes greater than 25° where side-cuts or box-cuts are necessary to increase stability and control (Stuart and Carr, 1991). In the RIL units, side cuts were, however, restricted to between 20° and 35°, and bulldozers were not allowed to traverse slopes greater than 35°. This restriction has produced the desired results in reducing the amount of bladed surface (as well as the extent of skid trails) in the RIL units. The restriction on wet-weather skidding in RIL areas also contributed to the differences. In part, the reduction of bladed surface in RIL units was also attributed to bulldozers required to traverse over the ground surface whenever possible minimising blade work on the soil. The higher incidence of churned soils in the RIL units is indicative that this instruction has been abided. A higher incidence of churned soil in the RIL units has beneficial effects because it contained debris that are important for soil moisture retention, assist seed capture and increase seedling survival (Pinard *et. al.*, 1996). Conversely, the absence of a clear policy for side cuts as well as the construction and use of skid trails may be the cause of higher bladed surface in the CL units.

This study found that on moderately disturbed skid trails in both RIL and CL units, natural regeneration has established. In the RIL units, there was sufficient ground cover on the skid trails after 6-12 months that suggested soil movement was stabilising. The presence of a churned soil may have provided the condition for ground cover to establish quickly. In addition, cross drains that were constructed to divert surface runoff also provided a soil stabilising effect as well as shelter belts behind their mounds for seedlings to establish. These mounds may help to stop seeds that had fallen on the skid trails from been washed away by overland water flow (Pinard and Putz, 1994). In the CL units, it probably took longer (10-12 months) for soil to stabilise judging from the density and height of ground cover that had re-established on the skid trails.

In the context of this chapter, the composition of ground cover that re-establishes on the openings is of importance for management and economic consideration. However, one-year-old skid trails in both RIL and CL units had ground cover comprising patches of mainly pioneer trees dispersed among weedy vines and herbs. This is also noticeable in older conventionally logged areas outside the study area where pioneer species constituted approximately 80-90 percent of tree saplings (>1 m tall <5 cm DBH; Pinard *et. al.*, 1996). Usually, the open conditions (high incident light levels) on skid trails or log landings favour invasion of pioneer tree species which are fast growing and able to compete with herbaceous weeds more efficiently than slow-growing dipterocarp species (Fox and Chai, 1982; Uhl and Jordan, 1984; Pinard and Putz, 1994). The latter are "intermediate" or "non-pioneer light demanders" species and their seeds are adapted to germinate in the dark and humid conditions of the primary forest understorey (Ng, 1978; Ashton, 1983). Other constraints to natural recovery of tree species include:

- the availability of mother trees near these openings which would have been removed during logging operations (many dipterocarp species have very poor seed dispersal, therefore distance to another tree is a key factor in their regeneration (Whitmore, 1984));
- the erratic mass fruiting pattern of dipterocarp species so that even if a mother tree is left adjacent to the openings, it may be many years before seeds are produced, and then, the incidence of seed predation in secondary forest is extremely high (Howlett and Davidson, 1996) and by then highly competitive weed species may already be well established;
- decreased soil porosity and water infiltration resulting from soil compaction adversely affecting growth (Van der Weert, 1974);
- low availability of soil nutrients which is a major factor limiting the establishment of dipterocarp tree seedlings (Nussbaum *et. al.*, 1996); this was because the removal of the first 15 cm of topsoil severely depletes the organic matter as well as nutrients (Lal, 1987); and
- exposure of topsoil to high temperatures that damage mycorrhiza essential to the survival and growth of seedlings (Lee *et. al.*, 1996).

On the basis that the success of plant recovery on skid trials in RIL units is still preliminary, faced with a host of uncertainties as highlighted above, and a likelihood that the openings will be re-used for intermediate surveys and inventories during the second felling cycle, the economic implication is not dealt with in this chapter quantitatively. However, if the forest in the RIL units would have recovered by the next cut, the benefits under this scenario would further enhance the appeal of RIL.

6.5 Conclusion

An additional benefit of adopting RIL techniques in harvesting tropical timber is that the extent of soil disturbance has been significantly reduced by nearly 60 % compared with areas logged conventionally, and within these areas the degree (intensity) of disturbance is greatly reduced thus accelerating forest recovery. Skid trails in RIL units had only half the amount of bladed surface compared with CL units. The requirements to achieve these reductions are a deliberate attempt to plan and execute the logging operations in such a manner as to reduce soil disturbance which has the intrinsic benefits of reducing on-site and off-site externalities. The opportunity cost of reducing unnecessary openings amounted to RM2,316 ha^{-1} without discounting. With a 2 % discount rate, the net present value would dropped by 70 % to RM706 ha^{-1}. At a higher rate of 10 %, the net present value would be reduced by about 333 times compared with undiscounted value. The present economic benefits of RIL might be improved further if the skid trails that had been churned did recover their economic production after the first felling rotation.

Chapter 7: Non-timber forest product

7.1 Introduction

Tropical forests are sources of a variety of non-timber forest products (NTFP) including rattans, fruits, medicinal plants, gums, resins, and essential oils (Myers, 1989; de Beer and McDermott, 1989). Most of these products provide food and materials for domestic use, while some of them also provide cash income when traded in local, national or international markets (Peters *et al.*, 1989; Choppra, 1993; Ganesan, 1993).

In this Chapter, the impact of logging on rattan as part of a wider economic analysis of RIL and CL techniques is evaluated. Rattan was chosen because it is the best known NTFP commodity in Sabah (Dransfield, 1984). There are over 100 species of rattan found in Malaysia in 13 genera of the sub-family of Calanoidae. Seven of the 13 genera of rattan comprising some 50 species are found in the natural forests of Sabah, Malaysia (Dransfield, 1984). The most important genus from a commercial point of view is *Calamus* which includes the majority of the 20-25 commonly sought-after species (Dransfield and Balick, 1988). Most of the remainder of the useful species are members of the genera *Korthalsia, Daemonorops* or *Plectocomia*. Rattan has multiple uses. Some parts of the plant are edible and the sap from the fruits of *Daemonorops* species is used as dye and medicine (PCARRD, 1985). The main part of the rattan that is of economic use is the stem. The stems are used either whole or split, to make fish traps, baskets, mats, hats, and walking sticks by indigenous people (Dransfield and Manokaran, 1993). Rattan is more widely best known as a raw material for furniture making. In 1987, Sabah exported 6,349 tonnes of rattan with a value of RM22 million. Since then, the quantity and value of the rattan trade has increased by 7 and 10 fold, respectively, based on 1994 figures (Statistics Department of Sabah, 1996). This increase in rattan trade is also evident for the whole of Malaysia where in 1990, the total value of rattan exported was RM69 million and increased to RM140 million by 1994. World trade in rattan and products has also increased at a phenomenal rate; from US$1.2 billion in 1980 to US$6.5 billion per annum, and is still expanding (Manokaran, 1990).

The following sections of the chapter outline the methodology used in assessing the rattan stocking in the study area, and the basis for estimating the growth and harvest yield as well as pricing and costing of rattans. From the results, several implications were drawn, among them, the comparative impacts between RIL and CL techniques on rattan stocking and composition; the value and significance of including NTFP in the overall economic evaluation of RIL techniques, and the problems associated with valuing rattan.

7.2 Materials and methods

7.2.1 Estimating rattan stocking in the study area

A post-logging inventory of the rattan resource was carried out in Parcel A in two logging units that were logged using RIL techniques (unit 32 = 47.7 ha; unit 35 = 57.4 ha) and another two units (unit 38 = 37.1 ha; unit 39 = 50 ha) logged conventionally. The total area for the four logging units was approximately 200 ha. These treatment units were selected based on similarity in terrain. The rattan inventory was carried out in the rectangular plots previously established for tree sampling on a systematic line-plot design but modified to suit rattan purpose (see Chapter 3 section 3.2). The rectangular plot is usually the preferred design as it gives lower sampling errors compared with grid or cluster designs (Nur Supardi *et. al.,* 1995). The size of the inventory plot for this study was 40 m x 20 m (0.08 ha), larger than the 0.01 to 0.025 ha plots recommended by some workers (e.g. Stockdale, 1994; Stockdale and Power, 1994; Nur Supardi *et al.,* 1995; Tandung, 1995). This would increase the precision of rattan estimates in the study area under logged-forest conditions. In each plot, all rattan plants taller than 30 cm were recorded by species, growth form (cluster or solitary), growth stage (mature or immature), length class, and habitat type. The cut-off height of 30 cm was imposed to ensure that only living rattans were recorded, and to reduce inventory cost. Rattans with many stems that are rooted in several places outside the plot are tallied as a unit in a plot if their root base is within the plot. In addition, extra care was taken to ensure that rattan with multiple rooting points from a plant was not double counted.

Forty-nine plots were established in the RIL units and 61 plots in the CL units. The uneven number of plots in the two treatment areas corresponded to the relative area of the units (RIL = 105.1 ha, CL = 87.1 ha). The plot data within each logging treatment were pooled for analysis after checking for normality.

There was no pre-logging inventory of rattan in the study area because logging had proceeded ahead of this study. In order to draw some implications about rattan density pre-logging, a co-variance analysis between rattan density and slope angle was undertaken. The main reason for looking at the slope correlation is to explore the potential impact on rattan stocking of the difference between RIL and CL in their prescription for what slope angles can be logged. The slope and rattan density correlation was also to examine if there is a need to adjust the inventory results for this factor because of differences between the plots in the proportion of area in each slope class. Slope angle was categorised into three classes with class I having slope angles between 0°-25°; class 2 with angles from 25°-35° and class 3 with angles above 35°.

7.2.2 Estimating rattan growth and yield

Rattan growth depends on a number of factors ranging from species to site factors. Many aspects of this relationship have yet to be studied satisfactorily (Dransfield, 1992). For example, light requirement is the single most important factor which limits the growth of rattan species (Manokaran and Wong, 1983), and is still little understood particularly in the natural forest environment which has a wide range of light conditions due to different canopy gaps, such that only broad generalisations can be made. The lack of understanding of rattan growth in relation to light and other factors has been reflected in the inconsistent growth rates reported in various references for the same rattan species (Table 7.1). Presently, most growth data reported are from silvicultural trials under plantation conditions of a few selected species namely *C. manan*, *C. caesius* and *C. trachycoleius* (Dransfield, 1992). There is little or no published information for rattans growing in the wild (Dransfield and Manokaran, 1993).

Generally, rattans that produce a solitary shoot or cane (e.g. *Calamus manan* and *C. subinermis*) have a large stem (>18 mm diameter) with growth rates of between 1 and 3 m length per annum and they mature in 12-15 years under a plantation regime (Aminuddin *et. al.*, 1992). Rattans which can produce multiple shoots or canes are often called 'clumps', 'clusters', 'stools' or 'genets' (Stockdale, 1994). They are capable of reproducing vegetatively from rhizomes or suckers and the diameter of each cane in a clump is usually less than 5-8 mm (e.g. *C. caesius* and *C. trachycoleus*). Small diameter rattans generally mature faster than large ones giving rotations of 5-8 years planted under fairly open forest canopy or existing forest plantation (Tan and Woon, 1992). The period of maturity for naturally growing small diameter rattan in Coorg (India) was reported to be five years (Badhwar *et. al.*, 1957). Growth rates of 1.5 to 5.0 m lengths per annum have been reported by Tan and Woon (1992) in Malaysia.

For large canes such as *C. manan*, it has been suggested that harvesting would be carried out between 12 and 15 years after planting (Aminuddin and Salleh, 1986). Large diameter rattans can only be harvested once at maturity because they have only one leading shoot and cannot resprout. Small diameter rattans can re-sprout, therefore more than one harvest from the same cluster is possible (Siebert, 1993). Dransfield (1979) reported that for the small cane *C. trachycoleus*, initial harvesting would start at 7 to 10 years after planting and subsequent harvests can be made at 1-2 year intervals. In Indonesia, Tardjo (1986) reported that *C. trachycoleus* could be harvested 6 to 8 years after planting, while another small cane *C. caesius* was harvestable 8 to 10 years after planting; subsequently, harvesting could be carried out at 2-year intervals.

Harvesting yield also depends on several factors. During harvest, the uppermost part of the stem, usually 2-3 m long, is discarded. Wastage also occurs due to the immature portion of the stem being harvested or the mature portion getting entangled and left in the tree canopy. Studies carried out in Indonesia reported such wastage could amount to between 13 % and 29 % (Sinaga, 1986). In the case of Sabah, Malaysia, wastage was reported to be higher; about 30 % (ICSB, 1993b). Mortality also affects the harvest yield. There is very little information in the literature on rattan mortality or destruction following logging. In a plantation setting, however, rates of 5-15 % have been reported (Manokaran and Wong, 1983).

Based on the above review on rattans, some generalisations are made for this study. On the light factor, the residual forest in the CL units has a fairly open canopy due to the intensive logging undertaken in the area. This open condition favours rattan growth. In theory, rattans found in the CL units would be faster growing compared with those in the RIL units. Conversely, the RIL units have less opened canopy than in the CL units with less light entering the forest floor. However, rattan growth in the RIL units is likely to be better than in the CL units because of less damage to the soil; less weed competition; more even forest structure to provide support for rattan growth. These factors cannot be quantified, therefore, it is assumed in this study that these factors cancel each other out between the RIL and CL units (Healey, *pers.comm.*). In general, large diameter rattans grow slower than small diameter rattans with the former having a longer rotation (8-12 years) than the latter (5-8 years) by their inherent growth behaviour. It is also apparent that not all rattan plants or stems can be harvested because of natural mortality and wastage left on-site or destroyed by logging. With these points in view, the following assumptions about growth rates, harvest rotations, mortality, wastage were adopted for the economic analysis:

a) Light regimes are assumed to be similar in the RIL and CL units after logging. Although the CL units have more opened canopy which favours rattans establishment and growth, this gain may be offset by more seed plants in ril units because of the lower harvesting disturbance to the forest (this assumption is upheld throughout the time frame of analysis on rattans)
b) Growth rates for small and large diameter rattans are 3.0 m yr^{-1} and 1.5 m yr^{-1}, respectively, based on published information
c) Age of initial harvest for small and large diameter canes is 8 and 12 years, respectively. After the first harvest, small diameter rattan would be harvested at two-year intervals, and large diameter rattan at 12-year intervals
d) Wastage is estimated at 30 % (assuming there is no difference between treatment areas even though RIL forest may be less swamped by weeds, climbers etc)
e) Rattan mortality is assumed to be 10 % for both RIL and CL units at every harvest

Using the above assumptions, the net harvestable yield of a small or large diameter rattan at maturity is calculated by estimating the total stem length per cane at maturity by multiplying its annual growth rates by its maturity age. In the case of small diameter canes, for example, the total stem length is the sum of all the stem lengths in a clump assuming that they grow at 3.0 m yr^{-1} per clump. After allowing for wastage (30 %), the net total length per plant is divided into 3 m lengths as the basis for pricing rattan (see section 7.2.3 on pricing). The net harvestable yield per hectare is then calculated by multiplying the number of 3 m lengths per plant by the number of plants per hectare after deducting 10 % for plant mortality.

7.2.3 Rattan trade and prices

Rattans are traded as whole canes (raw), semi-processed products that include peels and cores or as finished products such as furniture. In many countries, whole canes are sold by units of length, and traded in lengths of two to four-metres (RIC bulletin, 1989; Manokaran and Wong, 1983). Rattan may be bundled into 50-100 stems and converted to weight estimates by taking the mean weight per unit of length obtained from a sub-sample of stems.

The value of rattan cane would increase by several times when it is converted from raw to semi-processed or fully processed products such as furniture. For example, when raw large diameter canes are semi-processed, prices increased by 40-66 % from the unprocessed stage (Table 7.2). When whole canes are converted into cores or peels, the price increase is even higher, in the range of 141 – 600 %. Tan and Woon (1992) reported that *C. caesius* fetches an ex-farm price of RM3,000 per tonne of dry cane that is equivalent to 36,000 m length. This is equivalent to RM0.33 per 4 metre length. For *C. trachycoleus*, an ex-farm price of RM2,800 per tonne is equivalent to 42,000 m of dry cane. For large canes, the estimated ex-farm price per stem of 4-m length is RM1.67 or RM0.42 per metre (Tan and Woon, 1992). In Sabah, rattans of both sizes are sold per tonne and per length of dry cane. Large raw rattan is sold for between RM3,000 and RM7,000 per tonne and increases to RM5,000 to RM7,000 once semi-processed (Table 7.2). For small unprocessed rattan, the price is between RM3,300 and RM4,000 per tonne and upon being semi-processed, rises to RM5,000-RM8,000 per tonne. One metric tonne of rattan contained approximately 1,000 three-metre large canes and about 6,000 six-metre small canes (Table 7.2).

The appraisal in this study deals with only semi-processed whole canes that have been washed, sulphured and sun-dried (see section 7.2.4 for details). The valuation is based on per unit length of 3 m for large canes and 6 m for small canes following the trade

Table 7.2 Rattan prices in Sabah (ICSB, 1993b)

Items	RM per tonne	RM per cane
a) Large diameter canes (per 3 m length)		
Unprocessed`	3,000 - 5,000	3.00 - 5.00
Semi-processed	5,000 - 7,000	5.00 - 7.00
b) Small diameter canes (per 6 m length)		
Unprocessed	3,300 - 4,000	0.55 – 0.67
Semi-processed whole rattan	5,000 - 8,000	0.83 - 1.33
Rattan core	8,000 - 9,500	1.33 – 1.58
Rattan peel	22,000	3.67

convention in Sabah. To calculate the unit price per cane ex-factory for small diameter rattan, the selling price per tonne was divided by the total quantity in cane lengths per tonne.

7.2.4 Rattan harvesting and processing costs

The traditional method of harvesting rattans in the wild in Sabah is manual (Sim, 1975). Usually only one man is required to do the job equipped with a machete or *parang*. The mature rattan is cut at its base with a machete and pulled free from the tree canopy. The total length of a large diameter rattan stem may grow to as long as 17 m. In the case of small diameter rattan, stem lengths vary but up to 12 m have been reported. The process of dislodging the rattan stem from the tree canopy is a dangerous task because of the presence of spines in many of the commercial rattan species. It is also a difficult task because the spines on the stem and fronts entangle with supporting trees. Once the rattan is dislodged from the tree canopy, the soft upper part measuring 1-3 m is discarded. A 3 m *C. manan* weighs approximately 6 kg (Nur Supardi, 1992). The remaining portion is cut into suitable lengths for handling; either dragged along the ground or bundled (for small diameter canes) and carried to the roadside approximately 1-2 km away. Where a longer distance is involved, the harvesting crew will build temporary camps inside the forest to store their collection before carrying them out on scheduled dates. The rattan bundles are then loaded onto trucks and transported to sales points or processing stations usually near the town.

The green rattans extracted from the forest are normally dirty, and of mixed species, size and quality. Upon arrival at the processing shed, they are washed in a pond. Raw rattans are boiled for various reasons. Boiling helps to remove moisture, waxy materials, resins and gums, improves colour quality, texture and flexibility and helps to prevent fungal or insect attack (Casin, 1985). The raw rattan is boiled in diesel at a temperature of 60° C to 150° C. Immediately after boiling, the canes are washed with water or scrubbed with sawdust or rug sack to remove any dirt and excess oil. After the curing process, the rattan canes are left to dry in the open for 20-30 days. Studies conducted by Abd. Latif *et. al.* (1992) on *C. manau* boiled in diesel oil showed that the average amount of moisture removed immediately after boiling ranges from 17 % to 54 % from its green moisture content of between 76 % and 98 %. In many cases, rattan canes are subject to a process of sulphur fumigation to give quality in colour. The product that comes out from these various processing is known as semi-processed rattan (not yet converted to furniture products etc). The rattans are then transported and sold to interested parties. Rattan processing in this study refers to the above activities, which involve washing, drying, fumigating and grading of rattans into sizes.

Typically, the costs involved in harvesting and processing rattan would include the extracting and processing costs, transport and general charges. In this study, the costs of extracting and processing rattans vary with the diameters of the canes (Table 7.3 and 7.4). For semi-processed large canes per six-metre length, the rates range from RM1.00 to RM3.00 with a mean value of RM1.50. These costs include labour and equipment charges, and delivered to the factory. For semi-processed small canes per three-metre length, the rates are between RM0.20 and RM0.45, and averaged RM0.30 per cane. Transport costs averaged RM0.40 per cane which include the delivery of rattan from forest to the factory. General charges averaged RM0.10 per cane for large and small diameter canes which covers administrative overheads. The final cost component is duties payable to the government (although they are transfers, not real cost).

7.2.5 Costs and benefits analysis

7.2.5.1 Harvesting cycle

The economic time frame of interest to this study is 60 years. This is the felling rotation for trees when a second cut will be made (see chapter 4). In contrast to trees, rattans have a much shorter felling rotation. For small canes, the initial harvest is made at year 8 and the subsequent harvests are at two-yearly intervals (Figure 7.1). Although the two-year intervals have been reported for cultivated small diameter rattans (Manokaran and Wong, 1983), this harvest frequency would not necessarily preclude naturally grown rattans if the forest conditions are left to recover from logging disturbance. In the study areas, the CL units had a fairly opened canopy which allows sufficient light to reach the forest floor preferred by rattans. The RIL units, however, will also sustain rattan growth because there is a higher stocking of rattans resulting from less logging disturbance. On these grounds, a total of 27 harvests can be made within a 60-year period with the first harvest at year 8 and subsequent harvests at a two-year intervals.

For large canes, this study assumes that an initial harvest will be made at year 12 and repeated every 12 years until year 60 with minimal investment in tending operations. The 12-year harvest cycle is sustainable given the good rattan stocking in the RIL units, and it has been reported that *C.manan* are also capable of re-sprouting (Manokaran, 1981). On this basis, there would be five harvest cycles within 60 years.

This study also assumes that the initial rattan stocks and growth rates in the RIL and CL units do not converge by year 60 (this is consistent with the results of forest growth modelling in chapter 4: Table 4.16). The basis of this assumption is that even though the CL units with its fairly open canopy would favour growth of rattans, the extent and conditions of the openings for roads, skid trails and log landings would not

Table 7.3 Cost of extracting and processing naturally grown rattan in Sabah

	Species	Processing Stage	Diameter (mm)	Unit[+] Cost (RM)	Handling[+*] Charges
A	Large canes (per 3 m length)				
A.1	*Calamus subinermis*	unprocessed	18 +	1.50-1.70	0.40
		semi-processed	18-21	1.00-1.50	0.40
			22 +	1.90-2.00	0.40
A.2	*C. ornatus*	unprocessed	18-29	0.80-1.10	0.40
			30 +	1.20-1.50	0.40
		semi-processed	18-29	1.30-1.50	0.40
			30 +	1.60-1.70	0.40
A.3	*C. scipionum*	unprocessed	1-29	0.30-0.50	0.40
			30 +	0.80	0.40
B	Small canes (per 6 m length				
B.1	*C. caesius*	unprocessed	5 +	0.20-0.30	0.10
		semi-processed	5 +	0.40-0.45	0.10
B.2	*C. praetermissus* }	unprocessed	5 +	0.20-0.30	0.10
	C. javensis }	semi-processed	5 +	0.20-0.45	0.10
	C. blumei }				

+ These values are per 3 m for large canes and per 6 m for small canes
* Handling charges include sizing, grading and bundling costs.

Table 7.4 Rattan costs used in the present study

Activity	Large cane (RM) (per 3 m length)	Small cane (RM) (per 6 m length)
1. Extraction	1.50	0.30
2. Processing costs+	0.40	0.10
3. Transport cost*	0.10	0.10
4. General overheads	0.10	0.10
5. Duties	0.10	0.10
Total costs	**2.20**	**0.70**

+ The processing costs adopted in this study is the average value to extract and process naturally grown rattan sizes ranging from 18-25 cm DBH) shown in Table 7.3

* The transportation costs is also an average charge for transporting rattan harvested from the wild and the cost is chargeable from roadside to the final destination

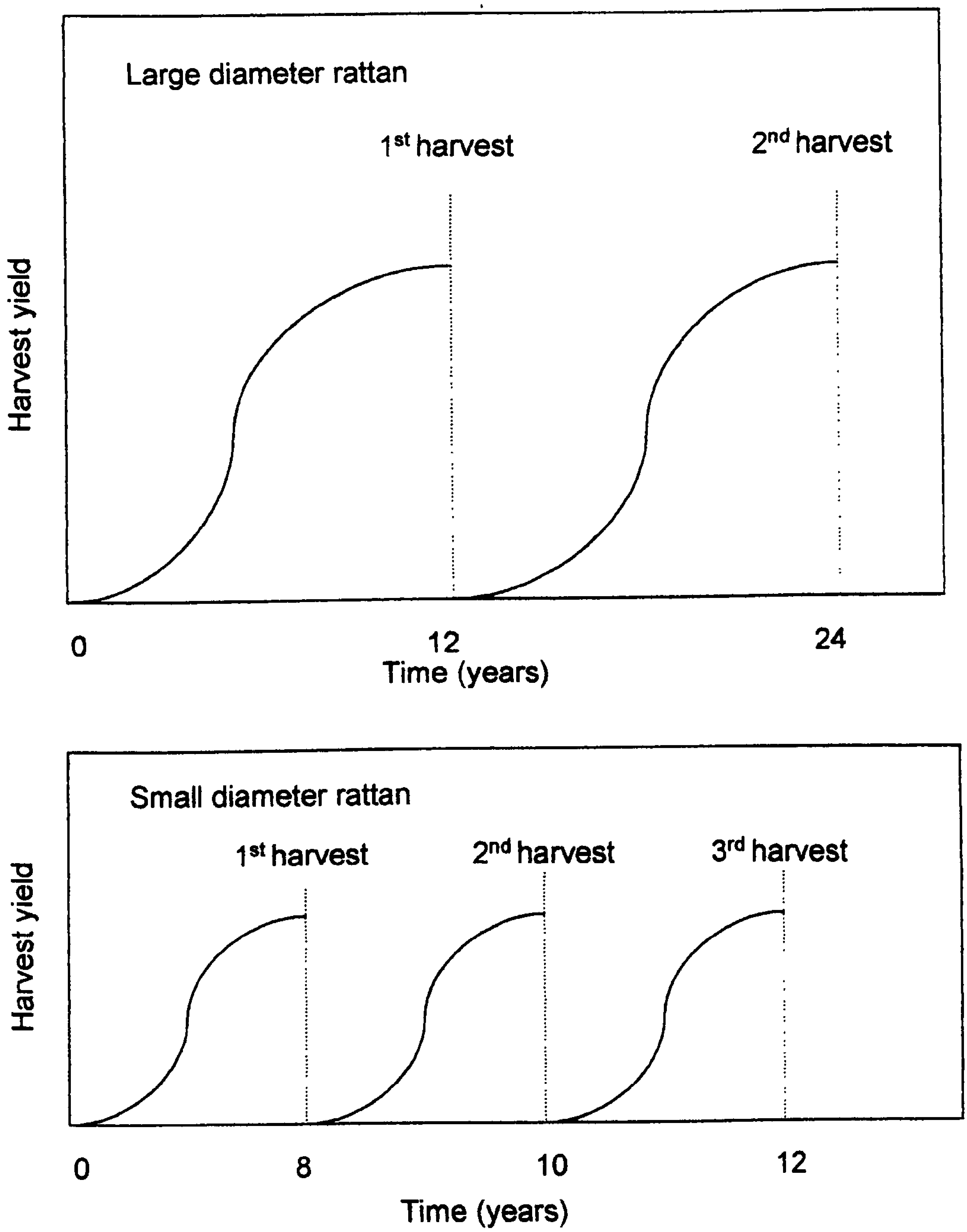


Figure 7.1 Schematic diagrams showing harvesting timing for large diameter rattan (top) and small diameter rattan (bottom). The initial harvest for large and small diameter canes is made at year 12 and 8 followed by 12-yearly and 2-yearly intervals. Within 60 years, large and small diameter rattan had five and 27 harvest cycles, respectively

recover fully within the time frame of this analysis (60 years) to enable rattans to re-establish. In the RIL units, the smaller openings and less disturbance would continue to be a better environment for rattan through the 60-years rotation, therefore, maintaining the gap between the RIL and CL units.

7.2.5.2 Evaluation

The evaluation of rattan benefits and costs is carried out with and without discounting. With discounting, the discount rate adopted was between 2 % and 10 % (at 2 % intervals). This range of discount rates includes rates that have been used by others in evaluating the financial feasibility of establishing rattan plantations which usually falls between 7-10 % (e.g. Shim, 1985; Nur Supardi and Wan Razali, 1989; Tan and Woon, 1992).

7.3 Results

7.3.1 Rattan stocking

The rattan species in the study areas belonged to three genera: *Calamus* (57 to 71 % of individual rattan plants per plot), *Daemonorops* (3 %), *and Korthalsia* (13 to 35 %) with a total of 12 species (Table 7.5). Of the *Calamus* species, only four out of the seven species have commercial value. Of these four species, only *Calamus subinermis* is a solitary cane of large diameter. All species in the *Daemonorops* (2 species) and *Korthalsia* (3 species) were non-commercial by present market demand. These non-commercial species (small diameter rattans) may become commercial in the future. In consideration of this point, this study assumes that 5 % of the total non-commercial species would be harvested in the initial harvest scheduled at year 8.

The mean density of rattan plants in the RIL area was approximately 65 % higher than in CL areas ($mean_{RIL}$ = 51 ± stems ha^{-1}, $mean_{CL}$ = 31 ± 6 stems ha^{-1}) and the difference was significant ($t_{0.05}$=1.98, P=0.032; Table 7.5). The implications of this difference in rattan density between treatment areas (and the following results) are discussed in section 7.4.

In terms of length classes, 90 % of the rattan plants in both the RIL and CL units fall between 0-6 m (class I) with a mean value of 1 m tall, 9 % of the total between 6-12 m (class 2) and only 1 % that exceeded 12 m (class 3).

Most of the rattan plants in the study area are in the immature stage with 94 % of the total rattan stems in both the RIL and CL units falling into this category. Only 6 % of the total rattan plants enumerated were considered mature and ready for harvesting at

Table 7.5 Rattan stocking in the study site (stems taller than 30 cm)

	RIL				CL				RIL		CL		RIL		CL	
	Unit 32		Unit 35		Unit 38		Unit 39		Unit 32+35		Unit 38+39		Mean (32+35)		Mean (38+39)	
	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no	%	no.	%
1 Area of unit (ha)	48		57		37		50		105		87		53		44	
2 Number of lines	10		14		10		11		24		21		12		11	
3 Total number of plots	24		25		28		33		49		61		25		31	
a) number of plots with rattans present	21		18		17		25		39		42		20		21	
b) number of plots with rattans absent	3		7		11		8		10		19		5		10	
4 Total number of rattan plants	96		102		71		80		198		151		99		76	
5 Mean number of rattan plants per ha	50		51		32		30		51		31		25		15	
6 Species (number of rattan plants)																
a) Commercial species																
Calamus subinermis (batu)+	18	19	17	17	8	11	4	5	35	18	12	8	18	18	6	8
C. caesius (sega)*	1	1	0	0	0	0	0	0	1	1	0	0	1	1	0	0
C. javensis (pipit)*	12	13	6	6	5	7	0	0	18	9	5	3	9	9	3	3
C. blumei (riman)*	23	24	0	0	9	13	15	19	23	12	24	16	12	12	12	16
Sub-total Large canes	18	19	17	17	8	11	4	5	35	18	12	8	18	18	6	8
Small canes	36	38	6	6	14	20	15	19	42	21	29	19	21	21	15	19
7 b) Non-commercial species																
C. acuminatus (peladas)	20	21	14	14	23	32	32	40	34	17	55	36	17	17	28	36
C. zonatus (kikir)	0	0	0	0	0	0	3	4	0	0	3	2	0	0	2	2
C. muricatus (lasikan)	0	0	1	1	5	7	3	4	1	1	8	5	1	1	4	5
Daemonorop sabut (cincin)	5	5	7	7	5	7	19	24	12	6	24	16	6	6	12	16
D. fissa (jagung)	0	0	5	5	0	0	0	0	5	3	0	0	3	3	0	0
Korthalsia echinometra (merah)	1	1	0	0	1	1	3	4	1	1	4	3	1	1	2	3
K. furtadoana (udang)	13	14	30	29	7	10	1	1	43	22	8	5	22	22	4	5
K. jala	3	3	22	22	8	11	0	0	25	13	8	5	13	13	4	5
Sub-total Small canes	42	44	79	77	49	69	61	76	121	61	110	73	61	61	55	73
8 Growth stage																
number of immature rattan plants	90	94	100	98	65	92	74	93	190	96	139	92	95	48	70	46
number of mature rattans	6	6	0	0	6	8	6	8	6	3	12	8	3	2	6	4
9 Length class (number of plants)																
Class 1 (0-6 m)	86	90	92	90	63	89	72	90	178	180	135	89	89	90	68	90
Class 2 (6-12 m)	9	9	10	8	8	11	8	10	19	17	16	11	10	9	8	10
Class 3 (>12 m)	1	1	0	0	0	0	0	0	1	1	0	0	1	1	0	0

Note: % Calculated based on total number of rattan stems
+ Large cane
* Small cane

the time of inventory. This means that the rattan stock in both the RIL and CL units are not ready for harvesting even though some of them are matured (not economical to just harvest the small quantity of mature stems).

More than 83 % of the rattans were located along the mid-slope (25°-35°) which occupied approximately 30 % of the area of the plots. There was a weak regression correlation between density of rattan in the two treatment areas and slope angle (r^2_{RIL} = 0.001-0.036; r^2_{CL} = 0.03-0.06; Figure 7.2 and 7.3).

7.3.2 Harvest yield

For large canes, the total harvestable length per rattan plant would be 18 m at the end of the 12-year rotation based on growth rates of 1.5 m yr^{-1} (section 7.2.2) After allowing for 30 % wastage, the net yield per large rattan plant would be 13 m. This comprises 4.2 stem portions of the marketable length of 3 m. With 18 large-cane rattan plants per hectare in the RIL units and six rattan plants per hectare in the CL units after logging (Table 7.6), the total yields per 12-year rotation per hectare less 10 % mortality due to logging would be 68 and 23 three-metre lengths per hectare, respectively. With five harvests made within 60 years, the total yield in the RIL and CL units are 340 and 113 three-metre lengths per hectare.

Calculations on a similar basis for the small diameter canes yielded 60 and 45 six-meter lengths per hectare per harvest, respectively. This is based on an eight-year rotation, growth rates of 3.0 m yr^{-1}, and rattan density of 24 stems and 18 stems per hectare for RIL and CL, respectively (including 5 % of the non-commercial small diameter rattan that would become harvestable). The total yields for 27 harvests in 60 years are 1,633 and 1,225 six-metre lengths per hectare, for RIL and CL units, respectively (Table 7.6).

7.3.3 Economics

The average price per semi-processed large diameter cane per three metre length was RM6 (range: RM5-RM7 per cane; Table 7.2) calculated on the basis of the average price per tonne for rattan in Sabah and a tonne contained approximately 1,000 three-metre lengths of canes. For small cane, the average price was RM1.10 (range: RM0.83-RM1.33 per cane) and a tonne of rattan contained 6,000 six-metre length canes.

The harvesting costs for large diameter rattan ranged from RM0.30 to RM1.70 per six-metre cane and for small diameter canes were between RM0.25 and RM0.35 per three-metre cane (Table 7.3). The total cost estimates for large and small canes for this

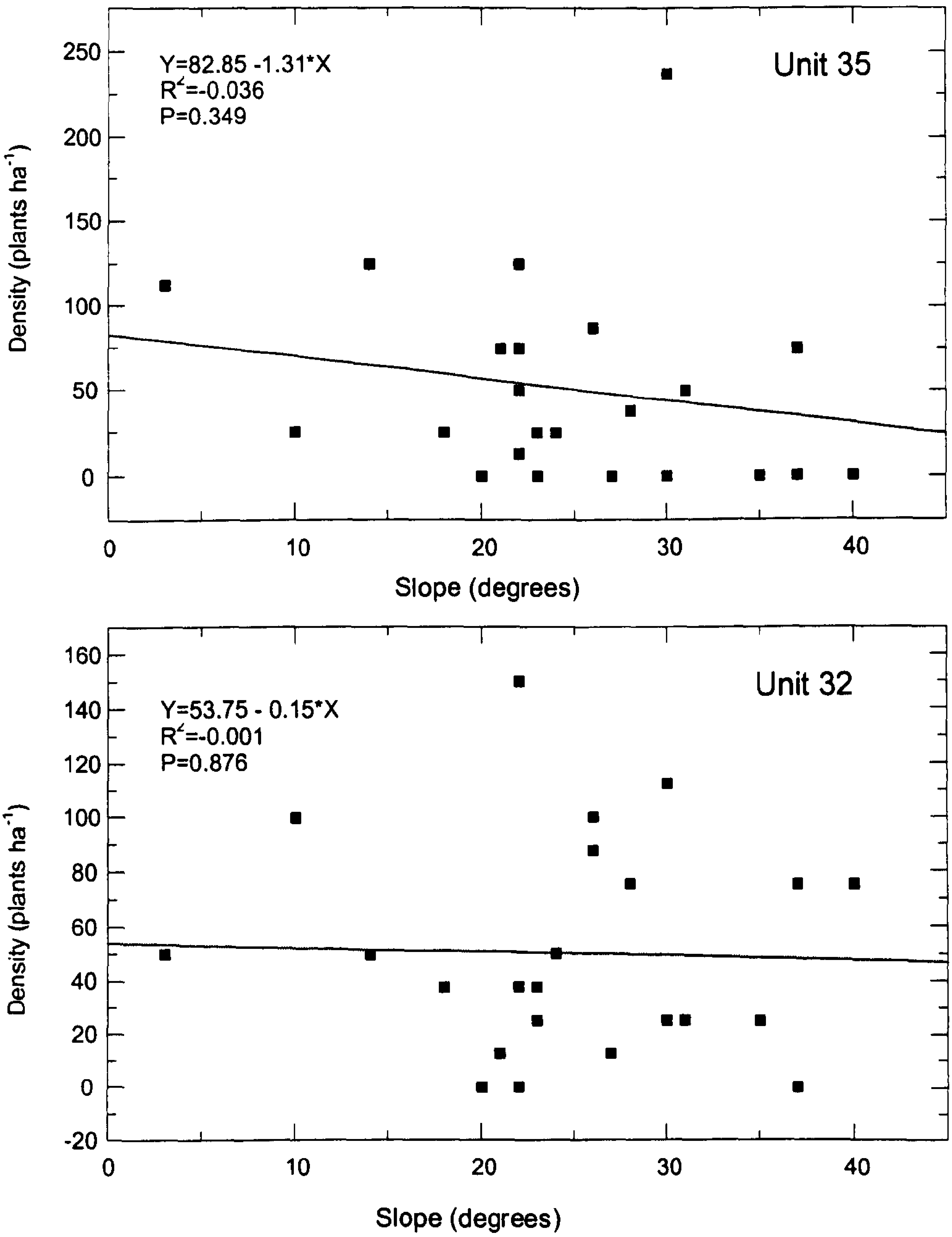


Figure 7.2 Relationship between rattan density (plants ha^{-1}) and slope angle (degrees) in two units logged with RIL techniques

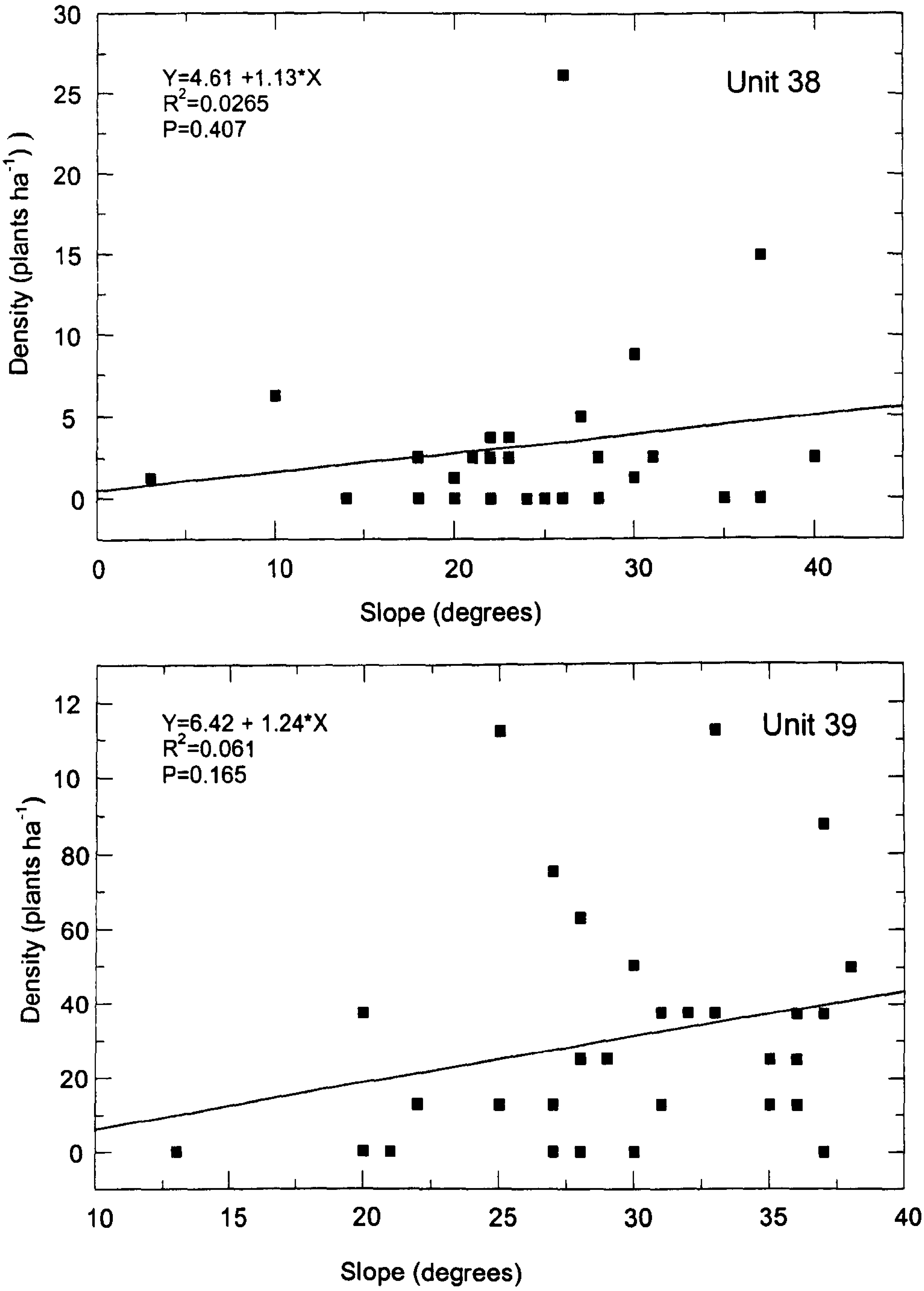


Figure 7.3 Relationship between rattan density (plants ha^{-1}) and slope angle (degrees) in two units logged with CL techniques

Table 7.6 Economic analysis for rattan in areas logged with RIL and CL techniques over 60 years with large diameter rattan having harvest rotations of 12-yearly intervals and small diameter rattan at 2-yearly intervals after initial harvest at year 12 and 8, respectively

		RIL	CL	RIL-CL	
1 Revenue (RM ha^{-1})					
1.1 Large canes (5 harvests in 60 years)		2,041	680	1,361	* See note 1
1 2 Small canes (27 harvests in 60 years)		1,796	1,347	449	
2 Costs of sales (RM ha^{-1})					
2.1 Large canes (5 harvest in 60 years)		748	249	499	* See note 2
2 2 Small canes (27 harvests in 60 years)		1,143	857	286	
3 Profit (RM ha^{-1})	@ 0%	1,946	921	862	* See note 3
	@ 2%	1,019	485	534	
	@ 4%	595	284	311	
	@ 6%	380	182	198	
	@ 8%	259	124	135	
	@ 10%	185	89	96	

Assumptions.

	Large canes (3 m)	Small canes (6 m)	
4 Rattan prices (per cut length)	6.00	1.10	* See note 4
5 Cost of sales	2.20	0 70	
5.1 Extraction	*1 50*	*0.30*	
5.2 Processing costs	*0.40*	*0.10*	
5 3 Transport cost	*0.10*	*0 10*	
5 4 General overheads	*0.10*	*0.10*	
5 5 Duties	*0 10*	*0.10*	

	Large canes		Small canes		
	RIL	CL	RIL	CL	
6 Density (plants ha^{-1}) in study area (at year 0)	18	6	24	18	* See note 5
7 Growth and yield assumptions					
7 1 Mean annual length increment per plant (m)	1.5	1 5	3	3	
7 2 Rotation (years)	12	12	8	8	
7 3 Number of harvests within 60 years	5	5	27	27	
7.4 Plant mortality at harvest time (%)	10	10	10	10	
8 Marketed length (m)	3	3	6	6	
9 Wastage (%)	30	30	30	30	
10 Calculations					
10.1 Total stem length (m) per plant at harvest	18	18	24	24	* See note 6
10.2 Stem length (m) harvestable per plant (less wastage)	12.6	12 6	16.8	16.8	* See note 7
10.3 Number of stem lengths (m) harvestable per plant	4 2	4.2	2.8	2.8	* See note 8
10 4 Total stem length (m) harvestable from 1 ha	340.2	113.4	1633.0	1224.7	* See note 9

Note:

1 Rattan price per length (item 4) multiply by total stem length harvestable from 1 ha (item 10 4)
2 Cost of rattan per length (item 5) multiply by total stem length harvestable from 1 ha (item 10 4)
3 Basis of caluculation: Sum of item 1.1 and 1 2 minus sum of item 2.1 and 2 2
4 For large canes, a selling price of RM6,000 per tonne was assumed containing 1,000 cane lengths (ICSB, 1993)
For small canes, a selling price of RM6,000 per tonne was assumed containing 6,000 cane lengths (ICSB, 1993)
5 For small canes, 5 % of non-commercial species was assumed to become commercial at each harvest With mean stocking at year 0 (non-commercial species) of 61 and 55 plants ha^{-1} in the RIL and CL units, this gives 3 plants ha^{-1} for each unit (Table 7 5). These were then added to the commercial stocking at 21 and 15 plants ha^{-1} in the RIL and CL units, respectively, to give the totals of 24 and 18 plants ha^{-1}
6 Basis: Mean annual length increment per plant (item 7.1) multiply by rotation (item 7.2)
7 Basis: total stem length at harvest per plant (item 10 1) less wastage (item 9)
8 Basis· harvestable stem length per plant (item 10.2) divided by marketed length (item 8)
9 Basis: number of harvestable lengths per plant (item 10.3) multiply by the density of harvestable plants (item 6 less item 7 4) and the number of harvests within 60 years (item 7.3)
10 Discounting formula ==>

$$\frac{N}{(1+i)^T - 1} \times \left(1 - \frac{1}{(1+i)^F}\right)$$

where i = discount rate
N = value of harvest at T
T = length of rattan cycle (Large cane at 12-yealy intervals; Small cane first year at year 8 followed by a two-yearly intervals (total of 27 cycles in 60 years)
F = length of felling cycle (60-years)

Note: This formulae is not applicable to small rattan because the initial delay is more than the length of cycle study were RM2.20 per stem portion and RM0.70 per stem portion, respectively (Table 7.4).

For each large and small diameter cane, the profits are RM3.80 and RM0.40 per cane, respectively. Working with the total rattan density in the RIL (230 ha) and CL units (176 ha) and the number of harvest cycles in each unit (no discounting), the combined revenue for large and small rattan from the RIL units (RM3,837 ha^{-1}) was higher than from the CL units (RM2,027 ha^{-1}; Table 7.6). In terms of costs, the combined small and large diameter cane in the RIL units (RM1,891 ha^{-1}) was higher than that from the CL units (RM1,100 ha^{-1}).

The profits (revenue - costs) made from sales of rattan in the RIL and CL areas were RM1,946 ha^{-1} and RM921 ha^{-1}, respectively for a 60-year projection without discounting (Table 7.6). The net difference between RIL and CL units was RM862 ha^{-1}. With a 2 % discount rate, the net difference reduced to RM530 ha^{-1}. At 8 % discount rate, this amounted to RM134 ha^{-1}.

7.4 Discussion

The residual rattan stocking in the study area (a range of 31 to 51 plants ha^{-1} in the four units) was comparable to the findings of Abdillah and Phillipps (1989) carried out in a logged-over hill dipterocarp forest in Sabah (even though the rattan inventory from the present study include only rattan above 30 cm height); they reported residual rattan stocking of 60 plants ha^{-1}.

However, it was significantly lower than those found in primary forest; the range of rattan stocking in primary forests was 341 to 371 plants ha^{-1} in Malaysia (Nur Supardi *et al.*, 1995); 228 plants ha^{-1} in Brunei (Stockdale, 1994); and 146 to 812 plants ha^{-1} in the Philippines (Tadung, 1995). While it is well known that there are major problems associated with rattan inventory (e.g. the multiple rooting points of many individual plants which leads to difficulty in determining the number of individual plants actually present in the area), it does imply that harvesting of timber seems to massively reduce rattan stocking. The clearance of forest area for skid trails, log landings and roads would certainly remove all the rattan plants in these areas. It has been reported that up to 40 % of the logging area would be used for these purposes although much less of the area was found in the RIL and CL units (7-17 % of total logging area; chapter 6). In addition, felling and skidding activities could also add to the destruction of rattan plants.

The post-logging inventory results from this study also showed that the density of rattans in the RIL units was 65 % higher than in the CL units. It is unlikely, although not impossible, that pre-logging differences in stem density between treatments explain the RIL and CL difference since the rattan inventory was conducted in two independent plots for each treatment. The results of the covariance analysis between slope angle and rattan density showed that logging has greater effects on rattan density located in slopes between 20°-35°, albeit the relationship was a weak one (r^2 below 0.06 for all four logging units). This means that where areas are loggable, RIL has reduced the destruction of rattan plants.

On the basis of the various assumptions used in the economic valuation, the potential profit from rattan harvests over a 60 year time frame (without discounting) from the RIL and CL units was RM1,946 ha^{-1} and RM921 ha^{-1}, respectively. The difference in profits was mainly due to differences in rattan plants in the RIL and CL units following logging, particularly, the lower density of large diameter canes in the CL units (three times) compared with that in the RIL units. Sales from large diameter canes contribute significantly to profits because of their higher value. Small diameter canes, on the other hand, were not as profitable although total stem length harvested was 5 to10 times higher than large canes. The net difference in profits between treatments amounted to RM862 ha^{-1}.

With a 2 % discount rate, the profits were RM1,019 and RM488 ha^{-1}, respectively for RIL and CL units. With an 8 % discount rate, the reduction in profit is much more drastic at RM259 ha^{-1} and RM125 ha^{-1}, respectively; a 75 % drop in value compared with a 2 % discount rate. This signifies the importance of the timing of costs and benefits; the further into the future, the lower is the net present value if high discount rate is used (Price, 1989).

Comparative economic data for rattan from natural forest is not available, particularly over the economic time frame (60 years) adopted in this study. Nevertheless, the net income from rattan reported in this study for both the RIL and CL units was approximately half of that reported for a plantation setting. For example, Tan and Woon (1992) reported that the net income per hectare per year for planted *C. caesius* was approximately RM3,129 ha^{-1} based on a planting density of 500 plants ha^{-1} on an 8-year harvest cycle, and harvestable cane length of 18 m. For large diameter cane, Aminuddin *et. al.* (1992) estimated that it would generate a net income per hectare of RM5,254 ha^{-1} based on stand density of 518 plants ha^{-1}; harvest once at year 15. One of the explanations for the disparity in economic values between studies was due to differences in rattan density. In general, rattan density in plantations is much higher compared with undisturbed natural forests; even higher for logged forests as in the case of this study.

In comparison with the economic value of non-timber forest products reported elsewhere, Peters *et al.* (1989) estimated that net economic value of fruits and latex alone from the Amazonian forest was US$6,330 ha^{-1} using a discount rate of 5%. This estimate has been criticised by subsequent authors who pointed out that the location of this study was atypical of Amazonia as a whole because it was close to a large urban market for forest products in the city of Belem (Southgate *et.al.*, 1996). The Peters *et. al.* was also criticised for not properly deducting harvesting costs. This return was supposedly higher than that of wood by three times. Choppra (1993) estimated that the net present value of non-timber goods and services from a deciduous forest in India varied between RM10,085 (US$4034) and RM16,655 ha^{-1}. The economic returns of NTFP including fruits, herbs and medicinal plants valued by the opportunity cost of collection method was RM1,503 ha^{-1}. However, these estimates are not directly comparable to the estimates for this study for several reasons. First, the revenue contribution obtained in this study was restricted to rattan while other studies cover a broader range of NTFP. Second, different authors used different harvesting cycles and discount rates in their analysis depending on their objectives. Third, there is large variation in values due to price, ecological and climatic conditions (Godoy *et. al.*, 1993). Fourth and not the least, there is the difference in methodologies applied by researchers.

7.5 Conclusions

It is clear from this study that using RIL techniques to harvest timber reduces the damage to rattans in the wild. The significance of this reduction in rattan density should be obvious since sustainable harvesting of rattan is dependent on the regeneration of the population from seedlings. In order to assess the scale of this gain, the potential economic values over a full 60 years was examined. This study found that using RIL to harvest timber could potentially yield a net economic benefit (RIL minus CL benefit) from rattan amounting to RM862 ha^{-1}. At a 2 % discount rate, this net benefit reduced to RM530 ha^{-1}. However, the results of the economic analysis should not be seen as fine-tuned numbers, but more as indicators of orders of magnitude which enable policy determination. Many aspects of the ecology of rattan have yet to be understood, in particular, rattan growing in the wild. For example, reliable inventory data on growth rates for rattans growing in natural forests are still hard to find. More precise research is also needed on the ecological requirements and functions of rattan species, and their regeneration rates in different forest types including logged over forests. The key consideration in this study is how long it will take for the rattan stocking in the CL units to return to the values in the RIL units. This information is valuable in predicting the time taken for rattan to return to pre-logging levels. Such information is also crucial for planning the controlled sustainable extraction of rattan from the forest.

Chapter 8: Water

8.1 Introduction

In chapter 6, the potential value of the timber at year 60 on the land representing the difference in area of landing sites and skid trails between RIL and CL was investigated. This chapter builds upon chapter 6. The potential economic implication of eroded sediment from these open spaces in the RIL and CL forest is investigated in line with one of the management objectives of the RIL project to reduce soil erosion. In discussing the impacts of forest activities on hydrological parameters, the importance of water yield or quantity and water quality cannot be over-emphasised. The following gives a brief review of the subject matter.

When forest cover is totally or partially removed, the total volume of rainfall reaching the forest floor increases because interception loss is decreased. The rate of movement of water into the soil is often reduced by a lower infiltration capacity (often associated with soil compaction), so surface runoff is increased. The rate of losses of soil water by evapotranspiration (due to reduction in leaf area and tree root lengths) is also reduced (Bruijnzeel, 1990). Studies in both temperate areas and in the tropics on conversion and removal of forest cover to other land uses characteristically revealed increased in water yield over time following logging treatments (e.g. Gilmour, 1977; Hsia and Koh, 1983).

Similar impacts of selective logging on water yield have also been reported from Babinda, Queensland, Australia (Gilmour, 1977) and Berumbun, Negri Sembilan, Malaysia (Abdul Rahim and Harding, 1992). The latter study is of particular relevance here because it compared the effect of supervised and unsupervsied logging operations on water and sediment yields. This study revealed that there was a significant increase in total annual water yield by both logging methods compared with the pre-logging condition. Over the first three years after logging, the mean increase was 87 mm y^{-1} (36%) in the catchment with supervised logging (in which 33% of the standing commercial timber was extracted), and 160 mm y^{-1} (65%) in the catchment with unsupervised logging (in which 40% of the standing commercial timber was extracted). However, change in total annual water yield is rarely the most economically important result of land use on catchment processes. Instead, the impact on storm flow (potentially leading to downstream flooding during the wet season) and dry season base flow are usually of greater significance, and neither of these variables reflecting the flow regime is generally well correlated with total annual water yield (Bruijnzeel, 1990).

Like Gilmour (1977), Abdul Rahim and Harding (1992) found that neither type of logging method produced a significant effect on peak flow (and thus downstream flood potential). They suggested two explanations for this. Firstly, that the proportion of the forest cover removed by the selective logging was too low to influence peak flow (effects on peak flow generally only occur following extensive clear felling or by conversion to different land uses (Bruijnzeel, 1990)). Selective logging (even conventional logging) leaves substantial areas of the forest undisturbed and causes minimal disturbance to the flow channels (Zulkifli *et al*, 1991). Secondly, peak flow is influenced by the pattern of rainfall, its duration and intensity, catchment water storage, underlying geology and soil characteristics of the area as well as land use. The complex interaction of these factors will control the impact of land use change on flow regime.

As in the case of several other studies (Bruijnzeel, 1990), Abdul Rahim and Harding (1992) found that most of the increase in total annual water yield following logging occurred during dry season, base-flow conditions. However, the impact of land use change on base flow is complex and depends on the balance between changes in the rates of water infiltration and evapotranspiration, as well as on the length of the dry season (Bruijnzeel, 1990). If the dry season ends before the water stored in the forest/soil has fully discharged then base flow might be reduced following logging that reduced infiltration rate (and storage capacity). However, if the dry season continues until after the water stored in the forest/soil has been fully discharged then base flow would be increased following logging that reduced evapotranspiration rate.

Abdul Rahim and Harding's (1992) study continued over three years and they found that the magnitude of the increases in water yield after logging were strongly influenced by variation in annual rainfall. Taken together, these results, and those of the other studies reviewed by Bruijnzeel (1990) indicate that there is no straight forward basis for carrying out an economic analysis of the potential difference in catchment water yield between forests logged by conventional and reduced impact methods. Variation in the seasonality of the climate, underlying geology, soil type and logging methods between Abdul Rahim and Harding's study and the RIL project in Sabah mean that there is too high a risk of major error in extrapolating their results.

The more important implication of forest activities or clearance is the problem of environmental degradation that ensues with the increase in water yield, such as sedimentation and impairment of water quality. As explained earlier, the partial or total removal of forest cover increased the total volume of rainfall reaching the forest floor. If the infiltration capacity of the soil is low, most of the rainfall will be transformed into overland runoff (Ward and Robinson, 1990; Peh, 1980; Sinun *et. al.*, 1992). As a result of the increased flow, erosion processes such as sheet wash, rill, gully or mass movement are triggered and river channel erosion is aggravated. The magnitude, however, depends on several factors and interactions: rainfall intensity, duration, raindrop size, erodibility of the soil, and slope characteristics (Nearing *et. al.,* 1994).

The exposure of forest soils in forest gaps also sets rainsplash erosion into motion. The extent of rainsplash erosion, however, depends on the relationship between tree heights, litter cover, and precipitation. When raindrops are intercepted by vegetation, they coalesced on the leaves and form larger drops (Brooks and Spencer, 1995). The increase in the size of the raindrops led to an increase in their terminal velocity causing rainsplash erosion (De Ploey and Gabriels, 1980). The higher the impact velocity the greater the amount of soil splashed. The implication is that a high forest canopy is not beneficial for reducing splash erosion. Therefore, what is important about an intact forest is the vegetation cover layers nearer the ground and especially the cover of litter on the ground surface. Ross and Dykes (1994) working in dipterocarp forest in Brunei found that removal of the leaf litter and root mat under intact canopy resulted in a 38-fold increase in sediment yield. Nussbaum (1995) found that litter cover on compacted soil reduced erosion but the rates of erosion were still comparatively higher than in undisturbed forest.

Studies have also found that ground compaction resulting from the repeated passes of bulldozers over roads, skid trails and log landings caused reduced infiltration which accelerates soil erosion (Dias and Nortcliff, 1985). Douglas *et. al.* (1990) working in the Ulu Segama Forest Reserve found that poor infiltration rates on logging roads led to an increase in suspended sediment concentrations of 3-8 times higher than in undisturbed forest. Malmer and Grip (1990) found that infiltration rates on skid trails were reduced by almost 100 % compared to undisturbed forest. In Indonesia, newly made skid trails eroded at a rate of 11 t ha^{-1} yr^{-1} increasing to 13 t ha^{-1} yr^{-1} with use, and 3.2 t ha^{-1} yr^{-1} three years after being abandoned (Ruslan and Manan, 1980). However, the linkage between erosion on land surfaces and sediment discharge into rivers is not simple (Douglas *et. al.*, 1990). Often erosion on slopes moves material from zones of erosion to zones of deposition without the soil reaching a river. Therefore, increased erosion at the top of a slope may be of minimal importance. However, at the bottom of a slope it may be of great significance. In contrast, research has found that soil damage close to rivers has a massively more significant impact on river sedimentation. Thus of all the logging impacts damage to river banks will be by far the most important for sedimentation. e.g. due to skid trails or roads crossing streams or rivers without adequate drains; log jams blocking rivers causing bank erosion (e.g. following collapse of a log bridge); log landing sites being adjacent to rivers (Anderson and Spencer, 1991; Douglas *et. al.,* 1990). This has led to the development of a sediment delivery ratio as a convenient way to simplify the complex processes of catchment, in-channel and downstream relationships on sediment yield. The sediment delivery ratio is essentially a reduction factor commonly used in the investigation of the economic costs of downstream sedimentation. It is used in this study and the concept is discussed in detail in section 8.2.2.2 and 8.2.3 of this chapter.

The consequences of upstream logging disturbances are manifested either on-site or downstream (off-site). Much attention has been given in the literature regarding these impacts (e.g. Megahan, 1972; Gilmour, 1977; Salleh *et. al.,* 1983; Lai and Shamsuddin; 1985). Generally, the downstream effects take on a higher cost to society because of more economic activity downstream, and sedimentation impacts are felt by people who consume or use the water for various purposes (Gregerson *et. al.,* 1987). The deposition of sediment downstream also affects aquatic life, water quality for domestic and industrial use, clogs reservoirs, irrigation channels and drains and increases the risk of flooding (Hamilton and King, 1983).

The magnitude of these adverse effects has been quantified in economic terms using different valuing approaches for different objectives. Generally, on-site and off-site effects of soil erosion have been valued by the *change in productivity* in terms of fish or crop losses (e.g. Gregersen *et. al.,* 1987). Some workers have used the *replacement cost approach* or *expenditure avoided approach.* For example, Brooks (1982) estimated that the cost of fertilisers to replace nutrient losses in eroded soil by farmers in the Loukkos watershed in Morocco represented 88-177 % of the total watershed investment costs. Other methods include *costs of clearing reservoir sedimentation*, *change in hydropower production*, or *deterioration of water quality* and *quantity* (Gregerson *et. al.,* 1987).

Within the context of this study, the objective of reducing sedimentation in river water falls within the definition of catchment management: the process of formulating and implementing a course of action involving natural and human resources in a watershed to provide benefits that are desired by and suitable to society on the condition that soil and water resources are not adversely affected (Gregersen *et. al.,* 1987). In the RIL project, logging coupe YT2/93 is a logical unit for watershed planning because it is bounded by the upper Segama River, spanning 50 m wide to the west side, and steep mountains to the north and east with altitude ranging between 500 m and 700 m above mean sea level (Figure 2.6). To the South, the relief is less hilly but broken ridges still prevail with numerous creeks, streams and tributaries draining into the lower Segama river that ends at the north eastern coast of Sabah (Figure 2.6). With annual rainfall averaging 2,800 mm, the RIL project watershed is a potential source of downstream sedimentation solely from natural events (i.e. rainstorms), or increased by land-use disturbance such as logging.

The lower Segama river with a quality index of Class II (good quality; treatment required for water supply purposes; Murtedza, 1990) is inhabited by people who use the river for fishing, transportation, consumption etc. As one of the 13 main rivers in Sabah, the Segama river can be utilised for hydroelectricity generation (Sinun, *pers. comm.*, 1998). At present, hydroelectricity provides approximately 340,000 MWh or 30 % of the total electricity consumption in Sabah (Statistics Department of Sabah, 1996). It is a cost-efficient power generation method as compared to conventional diesel-operated generation which accounts for 70 % of Sabah's power generation requirements. With an increasing population and new housing, and the Government's policy to industrialise Sabah, the demand for more cheap power is expected to increase.

However, the generation of hydroelectricity can be adversely affected by river sedimentation. More sediment in the river water results in a reduction of volume in hydropower reservoirs, and also increases turbine wear and replacement. In the Philippines, Briones (1985) estimated that economic loses in hydropower production due to sedimentation from mining operations amounted to 10-12 % of the estimated total losses due to reducing hydropower production, and irrigation and increased flooding. In India, reducing sedimentation rates into reservoirs resulted in significant cost savings in dam construction; a reduction in 25 % in sediment export to the reservoir would allow the dam height to be constructed 0.53 m lower than the originally designed height of 37 m (Sinha, 1984). This reduced the cost of the dam by 4.5 %.

The growing demand for water in Sabah and the potential adverse impacts of uncontrolled logging on hydrological attributes call for increased attention to integrate watershed protection and sustainable timber production objectives. This chapter presents a case study that compares the benefits of *with* (RIL) and *without* (CL) catchment management in terms of the opportunity costs of forgone hydroelectricity. The main aim is to illustrate a logically consistent framework in which the economic significance of an environmental deterioration can be assessed. The importance given to valuing water benefits in terms of hydroelectric generation, rather than the benefits for human consumption (e.g. provision of drinking water or food sources for villages dependent on fishing) or industrial consumption of water (e.g. cost of treating water), was decided mainly by the time and budget constraints in getting the necessary economic data for assessing the potential off-site effect related to water.

8.2 Materials and methods

The economic framework of this study is based on the premise that logging causes soil disturbances and the eroded soil will eventually get into the river system and affect the hydroelectricity generation further downstream (Figure 8.1). The degree of river sedimentation could be lessened with RIL. To estimate the economic cost of forgone hydroelectricity, it is necessary to estimate sediment production from the

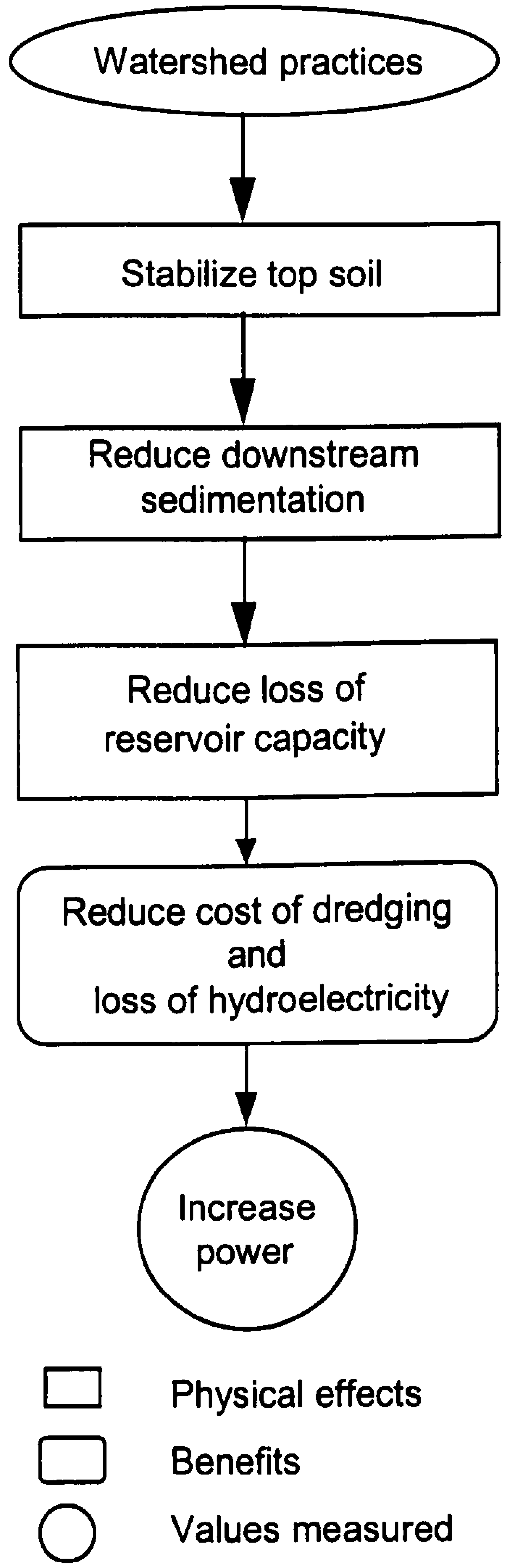


Figure 8.1 The physical effects and benefits from watershed managment practices

source to downstream. The sources and amount of eroded soil from the water catchment that reaches the hydroelectricity plant will depend on several factors such as rain intensity, particle size etc, which are discussed in the following sections. Secondly, there is a need to value the forgone hydroelectricity due to sedimentation. The basis for this evaluation is the opportunity cost of hydroelectricity when the plant is shut-down during the days that the water intake pond is dredged. This valuation approach has been used by Mohd Shahwahid *et. al.* (1998) in their economic valuation of watershed protection, but this study differed from the former in that several modifications were made to suit this study and the conditions in Sabah. The following sections describe the approaches and techniques for the economic analysis.

8.2.1 Choice of economic analysis

In analysing projects involving natural systems such as catchments, the *with* and *without* analysis is commonly used (Gregersen *et. al.*, 1987). A *with* and *without* analysis compares the situation with the project with that without the project. It is not the same as a *before* and *after* comparison. For example, poor land use in a catchment area leads to sedimentation in a reservoir. However, natural erosion processes of streambanks and streambeds also contribute to sediment load. The proper evaluation of a catchment management program is to determine the sedimentation rates *with* and *without* the project. A *before* and *after* analysis may give a misleading result, especially if naturally occurring erosion was increasing. In this case even the best catchment management program may not eliminate all sedimentation. On this basis, the *with* and *without* approach is used in this study.

8.2.2 Estimating sediment yield

8.2.2.1 Terminology

There are a few terms commonly associated with estimating sediment yield which originates from soil erosion. Soil *erosion* is often used as an all-inclusive word to describe the wearing down of a landscape. The precise definition, however, is the detachment or entrainment of soil particles closely associated with the hydrological cycle (Mutchler *et. al.*, 1994). The detachment process of soil particles is governed by the erosivity of rainfall, in turn governed by the intensity and, duration of rainfall and the mass, diameter and velocity of raindrops (Morgan, 1986). *Soil loss* is defined as the amount of soil lost in a specified period over an area of land. It is expressed in units of mass per unit area, such as t ha^{-1} or kg m^{-2}, for a single storm event, an average value for a number of years or for any other specified time period. Soil loss is of interest primarily in terms of on-site effects of erosion (Nearing *et. al.*, 1994). After detachment, soil particles are transported by surface flow.

Soil particles that suspend in solution are referred to as sediments. *Sediment yield or production* from a drainage basin is defined as the volume or mass of sediment that passes a designated point at the outflow end of a plot or watershed (Mutchler *et. al.,* 1994). It is commonly expressed as quantity per unit area and time in units of m^3 km^{-2} yr^{-1} or kg ha^{-1} yr^{-1} or tonnes km^{-2} yr^{-1}. In most cases, it refers to the suspended sediment load (particles greater than 45 micron in size) of the river which accounts for the majority of the total load (Walling, 1994). Sediment yield is important in terms of off-site effects of erosion, which is of interest in this study.

8.2.2.2 Measuring sediment yield

Two techniques for measuring sediment yield have been widely used in soil research investigations. Plot scale studies use bounded plots to collect runoff or sediment that is washed to the lower end of the plot. Runoff plots are commonly 2 to 8 m long and 1 to 2 m wide (e.g. Nortcliff *et. al.,* 1990; Ross *et. al.,* 1990). The justification for plot scale studies is their utility in studying the basic aspects of soil erosion in detail or to investigate soil erosion in different disturbance classes.

The alternative technique for measuring sediment yield is to collect water samples from streams draining an entire catchment at a point outside the catchment. Catchment scale studies are best for research that seeks to evaluate conservation systems or to verify a modelling concept (Mutchler *et. al.,* 1994). They have the advantage of providing a spatially integrated assessment of erosion rates in the upstream catchment area and thereby avoid many of the sampling problems associated with direct measurements (Walling, 1994).

The preference for catchment scale studies stems from research findings that not all soil loss in a catchment becomes sediment yield, as some of the particles are deposited or stored in the system. In the case of a forested catchment following logging disturbance, a large proportion of eroded sediment is temporarily re-deposited within the catchment (Douglas, 1992). The principal areas of sediment storage within a drainage basin are the hillslopes in surface depressions and valley floors. These stored sediments may be released only during storm events (Anderson and Spencer, 1991). Once in the river water, the sediments may accumulate or be trapped behind wood debris dams and be released only episodically, either by lift and floatation during major storm events or by failure through decomposition of log barriers (Douglas, 1992). The duration over which sediments are stored in a river is influenced by factors such as flow velocity, channel geometry and sediment properties.

Sediment yield collected at the outlet of a river basin can, therefore, provide a useful index of the net impact of the rate of erosion and soil loss in the watershed upstream. The ratio of sediment delivered at the basin outlet to gross erosion within the basin is termed the sediment delivery ratio (Glymph, 1954). The concept of sediment delivery has been expanded to cover "drainage basin sediment delivery" which lumps both the sediment delivery processes with the in-channel sediment delivery component. Basin sediment delivery ratio (hereafter SDR) is a convenient way to simplify the complex processes of drainage and sedimentation in cost–benefit analysis (Gregerson *et. al.*, 1987). Brooks *et. al.* (1982) derived SDR by firstly estimating the annual soil loss ($t\ ha^{-1}\ yr^{-1}$) using the Modified Universal Soil Loss Equation (MSLE) formulated as A = R x K x LS x VM where A = soil loss ($t\ ha^{-1}$); R=rainfall erosivity; K=soil erodibility factor; LS=topographic factor, and VM=vegetation management – erosion control factor (also see Mutchler *et. al.* (1994) for details). Subsequently, the weight of soil was converted to volume equivalent by multiplying it by the sediment density of a universal value of 1.6 tm^{-3}. However, the MSLE can lead to errors in the tropics when the results are compared with actual measurements as has been reported in some studies (e.g. Roose, 1977).

Although empirical models have been developed to predict SDR based on measured parameters such as basin relief, basin area, slope of main channel, annual runoff or gully density, they are of limited success in the specific sites studied (e.g. Williams, 1977). Based on compilation of existing studies, Hadley and Shown (1976) found that only 30 % of the sediment eroded in many of the small tributary basins (0.5 5.2 km^2) of the Ryan Gulch basin in north-western Colorado reached the main valley. Wade and Heady (1978) documented a range of sediment output between 0.1 % and 38 % of gross erosion for various catchments. Attempts to produce a universally applicable SDR model have also been unsuccessful (Walling, 1994). The failure to produce a generally applicable prediction equation for SDR is due partly to the complexity of sediment delivery processes and their interaction with catchment characteristics.

In the context of this study, both plot-based and catchment studies of soil erosion from logging disturbances have been conducted in the Ulu Segama Forest Reserve. These studies are briefly described in section 8.2.2.4. The sediment yield data from these studies provide a useful source of information to calculate the sediment delivery ratio for the Ulu Segama Forest Reserve. The basis of calculating the sediment delivery ratio is given in section 8.2.2.6.

8.2.2.3 Identifying main sources of soil erosion

When trees are harvested, their removal requires roads, skid trails and temporary log landings. These areas have been identified as the main sources of sediment yield in forested catchments (Dunne, 1977; Gilmour, 1977). Field studies carried out by Nussbaum (1995) within the Ulu Segama area indicated that disturbance resulting from bulldozer logging can be categorised into four main categories namely; roads, log landings, skid trails and extraction areas (Nussbaum, 1991).

Roads that provided the primary access for timber extraction represented the most extreme form of disturbance. During road construction, a substantial amount of soil was disturbed particularly where it involved side-cuttings of slopes. These created a large amount of side casts prone to be eroded during storms (Douglas, 1992).

A second category of extreme disturbance was log landings, which served as temporary log decks in the forest. These sites were prepared by scraping away the top soil, thus exposing the sub-soil in order to give traction to log loaders during loading and unloading of logs onto logging trucks. These landing sites are also subject to a very high density rate of movements by vehicles.

A third category of soil disturbance occurred on skid trails built for removing logs from the stump to the log landings. In the process of skidding, the front end of the logs is dragged along the ground, scouring the soil. The bulldozer operator often obtains ground traction during winching of the log by running the track into the ground, creating severe soil disturbance.

A fourth category of soil disturbance occurred in the extraction areas. These areas formed the largest portion of disturbed area but soil loss was not significant as the density of tractor passes was much lower, primarily to access the log at each stump. Therefore, this fourth category was excluded from the present analysis and only three disturbance classes namely, roads, skid trails and log landings were considered in the present study.

8.2.2.4 Source of sediment yield data

Within the Ulu Segama area, erosion research has been undertaken at the plot and the catchment scale. Two studies are of relevance to this study, and they are based on the work of Nussbaum (1995) and Douglas *et. al.* (1990). These studies investigate the impact of conventional logging on soil erosion.

Nussbaum (1995) studied post-logging soil erosion using erosion pins and runoff plots investigated over different periods. Erosion pins are metal rods which are inserted perpendicularly into the ground to measure the erosion and deposition of soil surrounding the pins. The length of the pin exposed above the soil surface (30 cm of the total length of

50 cm) is measured periodically, an increase indicating ground surface retreat which is recorded to be erosion, and a decrease meaning ground surface advance which is read as deposition. In a separate study, Nussbaum (1995) studied erosion using runoff plots which are bounded plots with edge barriers extended 25 cm above the soil surface. Across the bottom of the plot, a shallow trench was dug and a collecting trough installed leading to collecting buckets.

The erosion pins study covered a total area of 6 ha containing residual forest, log landings and skid trails set out in a grid of 250 experimental plots on five transects (replicates) covering five classes of disturbance (log landing, skid trail, debris piles, disturbed forest and undisturbed forest). Three erosion pins were inserted into the soil 1.0, 1.5, and 2.0 m for each plot. Changes in the exposed length of each pin were measured after 1, 2, 4, 6, 12, 18 and 24 months. After measuring each pin, all the surrounding litter and debris was carefully replaced. The erosion pin experiment was found to be effective in measuring soil erosion on log landings (bare soil) but was not suitable on skid trails where there is debris. Subsequently, another experiment using runoff plots to measure soil erosion was adopted by Nussbaum (1995).

With the runoff plots, six plots each measuring 3 m in length by 1 m wide were established in each of six disturbance types (3 for skid trails; 3 for forest plots – not replicated). Each plot was aligned with the slope of the hillside that had slope ranging from 5° to 15°. Runoff and sediment from the six runoff plots were sampled after most rainfall events and at least every 48 hours following a strict protocol over 10 months. On skid trails, one runoff plot was set up in each of three disturbance classes. The environment of the first skid trail class had all topsoil removed with only a little loose material remaining i.e. similar to a road or log landing environment. The second skid trail class had bare soil covered by debris consisting of the crowns of two sub-canopy tree species. The third skid trail class had loose churned material on the soil surface. Two other runoff plots were established in disturbed forest. One covered with debris consisted of part of the crown of a felled tree and several sub-canopy trees. The second plot consisted of intact understorey vegetation with no debris from logging operations. The sixth runoff plot was set up in undisturbed forest covered with its soil litter.

Prior to Nusbaum's (1995) study, a catchment scale hydrology project to examine the effects of tropical logging disturbance was undertaken in the upper reaches of the Ulu Segama river in 1987 (Douglas *et. al.*, 1990). One aspect of the project was to identify the sediment yield from three small forested catchments (of 0.56, 1 and 10 km^2). Two of the forested catchments (of area 1 km^2 and 10 km^2) were not disturbed by logging, while the third (of 0.56 km^2) was logged conventionally in stages between August 1988 and June 1989 and monitored over a 27-month period following logging. Within the logged catchment changes in suspended sediment load following each stage of logging activity, i.e. road construction, removal of trees and log skidding operations, were compared with one of the nearby undisturbed catchments (1 km^2). Sedimentation concentration and total water yield were measured in each catchment. The catchments were not calibrated *prior to* logging activity. The catchments had slopes of between 0° and 45°, these being within the range of slopes in the RIL Project site.

The two studies given above have some similarities and differences between them. Both studies were conducted in conventionally logged areas which provide useful references for the *without* watershed management option. Conversely, the two studies were not set up to measure sediment yields on a *before* and *after* logging scenario. Neither of these studies was a direct RIL versus CL comparison. Nussbaum's data represented the gross sediment produced on-site while Douglas *et. al.'s* work represented net sediment yield from the catchment. Of these two studies, Nussbaum's study using runoff plots was of interest to the present study because it provided sediment yields broken-down by different categories of disturbances compatible with the investigation of this study.

In the case of the *with* catchment management scenario, no hydrological impacts study was conducted within or outside the RIL project site or in the Ulu Segama area. The main reason was that the primary objective of the RIL study was to reduce logging damage to the residual trees and soils for carbon benefit, with no research interest in the hydrological or wildlife benefits. The assumption then was that RIL techniques would 'take-care' of the other environmental values since it was an environmentally-friendly harvesting system. The only detailed study ever conducted in the tropics that monitored the effects of 'supervised' and conventional logging methods on water attributes was that in Berumbun, Negri Sembilan, Malaysia (Abdul Rahim and Harding, 1992). However, the Berumbun data can not be applied directly here due to difference in the geographical, soil and hydrological conditions. Abdul Rahim and Harding's (1992) hydrological study would provide useful comparative estimates of results between the studies by Nussbaum (1995) and Douglas *et. al.*(1990) on sediment yield and concentration.

The primary difference between RIL and CL in the rate of sedimentation produced by the logging operations is that they differed in the proportion of forest area that was converted into skid trails and log landings. These areas were measured in the field and have been presented in Chapter 6. The log landings in the RIL units were about half the size of those in the CL units ($mean_{RIL}$ = 0.7 ha; $mean_{CL}$ = 1.7 ha; chapter 6, Table 6.1). Similarly, skid trails occupied a much smaller area in RIL than in CL units. The areal difference for skid trails between RIL and CL was about 80 % ($mean_{RIL}$ = 4.3 ha; $mean_{CL}$ = 21.0 ha; chapter 6, 6.1).

In addition to this major difference in the area of bare soil created, the difference in the RIL and CL techniques could be expected to create a difference in the rate of sedimentation resulting per unit area of bare soil. Actual sediment yield data from a *with* catchment management option (equivalent to RIL) were not available. Therefore, the impact of this effect was examined by assuming two estimates: a *high value* by assuming that the rate of sediment production per area was the same from RIL as from CL units; a *low value* by reducing the sedimentation rates in RIL to a lower level commensurate with the reduced damage caused to bare soil by this technique. However, the low values were applied only to skid trails and log landings because roads in both RIL and CL units were constructed using conventional guidelines, so it can be assumed that their conditions and locations and thus rate of sedimentation was the same. The justification and basis for presenting a low sediment value for RIL are as follows:

(a) There is a difference in soil erosion yield per area of log landing and skid trail in CL and RIL, i.e. erosion rates from the eroding area. The log landings in the RIL units were smaller than those in CL units, and constructed with a shallow slope angle to allow free flow of runoff. In contrast, the log landings in CL units were bigger and horizontal. In the RIL units, there was less skid trail overall, and less soil disturbance on these areas (i.e. more non-bladed surface). The total skid trails' length in the RIL units were shorter ($mean_{RIL}$ = 8 m; $mean_{CL}$ = 35 m; chapter 6, Table 6.2) by four times. In addition to the above, skidding operations were temporarily halted in the RIL units during wet weather. In the RIL units, cross-drains at various intervals along skid trials and roads were installed after the completion of logging operations. These cross-drains cut across skid trails or roads to divert and reduce the velocity of runoff on steep slopes. They were no cross-drains in the CL units. The impact of these factors on erosion rate can only be inferred from the degree of disturbance within the disturbance classes. The RIL units had only 38 % of the total skid trails categorised as bladed (exposed to sub-soil) compared with 87 % in the CL units; churned soils (which were better for growth but may have higher rates of soil erosion because they are loose) occupied a higher proportion of the area in RIL compared with CL ($mean_{RIL}$ = 50 %; $mean_{CL}$ = 11 %; chapter 6, Table 6.2; Nussbaum *pers. comm.*)

(b) There is a difference in the proportion of eroded soil from skid trails and log landings that enters a water course as sedimentation between CL and RIL (the sediment delivery ratio) due to differences in the location of these bare soil areas between the CL and RIL techniques. The log landings in the RIL units were located further away from water courses than in CL because of the buffer zones. Also, skid trails in the RIL units cross fewer water courses because of the buffer zones. Therefore, there is a greater probability of eroded soil in RIL being trapped in an area of deposition on the hillslope before entering a water course. In addition, it is known that damage to the banks of water courses makes a disproportionately large contribution to overall levels of sedimentation and this damage is expected to occur more frequently in CL. On these bases, the sediment delivery ratio per area of bare soil in the RIL units would presumably be lower compared with CL units. However, it was not possible to derive a quantitative estimation of this effect due to the absence of available data from the field or literature.

Based on the above, a difference in the rates of sedimentation per unit area of bare soil in RIL and CL was estimated. The results of these extrapolations are given in section 8.3.4.

8.2.2.5 Long-term sediment yield data

Various studies that monitored the impacts of logging on hydrological attributes have shown that soil stabilization or recovery was faster for 'supervised' logged areas. For example, the Berembun study in Malaysia reported that suspended solids and turbidity associated with conventional bulldozer logging remained high five years after logging. Conversely, the recovery period following supervised logging was only two years due to rapid re-establishment of ground cover (Baharuddin and Abdul Rahim, 1994). Douglas *et. al.* (1990) reported that suspended sediments from conventional logging operations for the Ulu Segama river in Sabah remained high three years after logging. Chapter 6 of this study showed that soil erosion in RIL units stabilised within 8-12 months compared with two years in conventionally logged units; the difference was explained by faster vegetation re-growth in the RIL units. The general consensus is that soil stabilises faster in supervised logging areas compared to unsupervised logging areas.

Actual long-term (60 years) data on sediment yield for this study were not available. To investigate the RIL and CL post-logging economic costs of sedimentation, the following approach and basis were used in modelling the time course of sedimentation rates for RIL and CL units:

(a) Estimate the time (years) when sedimentation from RIL and CL units would return to pre-logging levels (assuming zero sediment). Based on Pinard's study (1995), it would take 200-300 years for RIL to recover to pre-logging levels. Conversely, CL units would require a much longer time between 300-400 years. The mean of these two values were used for this present study i.e. 150 years and 350 years for RIL and CL, respectively

(b) Calculate the slope of the RIL and CL lines (hereafter called sediment recovery curve – SRC) for estimating annual sedimentation rates (see Appendix 8.1 for calculation)
(c) From the above, determine the annual sedimentation yield for a 60-year rotation, the economic timeframe of interest to this study

8.2.2.6 Estimating sediment delivery ratio

Nussbaum's data represented the gross sediment produced on-site while the present study was interested in the sediment yield in the river. To use Nussbaum's data it was necessary to apply a reduction factor to estimate the sediment yield in the river water. The reduction factor was calculated taking the ratio of the sediment yield data between Douglas *et al.*'s and Nussbaum's datasets, which gave the SDR for the Ulu Segama catchment. This ratio was calculated on a per area basis, expressing Douglas's *et al.*'s data per whole catchment area and Nussbaum's data per area of her plots for their logged treatments. The SDR for the Ulu Segama catchment was compared with SDR values from other catchments of similar size to check if it is within range and to indicate the confidence in using Nussbaum's sediment yield data.

8.2.3 Estimating sediment yield at the reservoir

At the reservoir, sediment capture in a reservoir depends on the trap efficiency of the reservoir, and is related to the size of the reservoir and the rate of flow of water into it (Magrath and Arens, 1989). Trap efficiency is the proportion of sediment retained in the reservoir divided by the total amount delivered to the reservoir. High river flow rates into small reservoirs serve to keep more silt in suspension and thus have lower trap efficiencies than large reservoirs receiving lower river flows. The standard approach in measuring sedimentation in a reservoir is to measure the water depth profile of a reservoir. This is done using sonar or other methods made before flooding. The change in volume over two measurements of water depth profile is then computed to give the change in water storage capacity loss to sedimentation. An alternative method is based on measurement of sediment loads of rivers flowing into and out of reservoirs, and the trap efficiency is then calculated. Studies by Magrath and Arens (1989) reported that the Karangkates reservoir in East Java had a trap efficiency of approximately 95 % using the latter method. Estimates of the trap efficiency for the Wonogiri reservoir in Central Java were of the order of 90 % (cited in Magrath and Arens, 1989). A more recent study in

Malaysia used trap efficiency of 70 % for three mini sediment ponds (ranging from 113 to 205 m^3) which serve as the water intake points for generation of hydro electricity (Mohd Shahwahid *et. al.*, 1998).

In this case study, the Sabah Pangi hydropower plant is the model for calculating the trap efficiency. The Pangi hydro power plant is located about 120 km south of Kota Kinabalu, Sabah. The project started in 1978 and was completed in 1984. It is a run-of-river type hydro power plant which uses the free water of the Padas River at a velocity of 40 m^3 s^{-1}, drained from a catchment of 7,815 km^2. The river flow is collected at a pondage with an effective storage of approximately 4.7 x 10^6 m^3. River water is diverted as it comes through the pondage via a diversion weir located approximately 2 km upstream of the power station. The diversion weir also diverts sediments and floating debris from upstream. Water passing the diversion weir is conveyed through a tunnel to gain a hydraulic head downstream and then channelled through steel penstocks to the power house for power generation. The intake structure comprises a settling basin and sand drain. The installed capacity of the Pangi hydropower plant is 66 MW with annual output of approximately 340,000 MWh. Sediment coming from upstream is collected at two locations: in the pondage area before the diversion weir and further downstream at the power station through a surge tank. Since the hydro power plant is a run-of-river type, the power generation is a direct function of the flow of the river water. During the dry season, the river flow decreases considerably and would affect the power generation.

Actual data of trap efficiency for the Pangi hydropower plant were not available. Given that the Pangi hydro power station was a run-of-the-river type (high flow rates into reservoir which keeps more silt in suspension), the trap efficiency would presumably be much lower than a conventional dam-reservoir such as that for the Karangkates reservoir and Wonogiri in Indonesia. This study assumes a 40 % trap efficiency (Harun, *pers. comm.*); half of that conventionally used in costing reservoir sedimentation (e.g. 70 % in Mohd Shahwahid *et. al.*, 1998). This conservative trap efficiency is also to account for the fact that the river is delivering sediments apart from the logged catchment i.e. from river bank erosion, stream channel and the likes, which is a complex matter still not well understood.

8.2.4 Valuing opportunity cost of hydroelectric power

The estimation of the opportunity cost of hydroelectricity is on the basis that sediments trapped at the pondage of the Pangi hydropower plant will decrease storage, hence affecting the proper functioning of the generation of power. To maintain the regular levels of water storage at the pondage, it would be necessary to dredge or remove the sedimentation accumulated in the pondage at appropriate intervals, at least once a year.

At the time when dredging is carried out, it is assumed that the hydro power plant will be shut-down, hence incurring forgone benefit through the loss in hydroelectricity generation, in addition to the costs of dredging.

For the economic valuation, the annual costs of dredging and loss of hydroelectricity over the time frame of analysis (60 years) need to be estimated. The cost of dredging includes hiring of excavators and lorries to remove the sediment from the pondage. The variables involved in the calculation of the dredging costs are the load capacity of excavator/lorry and the number of hours required to remove the sediment. The calculations were based on reasonable estimates, and not measurements as shown in Table 8.6.

To calculate the opportunity cost of hydroelectricity during shut-down for dredging, the variables needed are the hydro power output per hour (Kilowatt-hours [KWh]); the shut-down time, and the price of electricity per KWh. These variables were obtained from the Pangi hydropower plant.

From the above, the total costs of dredging and loss of hydroelectricity can be calculated for the 60 years, and the net present value obtained using discount rates ranging from 0 to 10 %. The per hectare costs were calculated by dividing the net present values by the area logged in RIL (129 ha) and CL units (175 ha).

8.2.5 Summary

The steps for estimating sediment yield production from the RIL and CL units, and the opportunity cost of hydroelectricity over 60 years are summarised as follows:

(1) Identify the source and extent of soil erosion from the RIL and CL units namely, roads, skid trails and log landings
(2) Determine the sediment yields for RIL and CL units for each category of logging disturbance following logging at year 1 (time=t_0) based on the work of Nussbaum (1995) and Douglas *et. al.* (1990). Two sediment yield values were adopted in RIL: a high sediment rate or value similar to the sediment yield per hectare disturbed of CL unit; a low value assuming RIL produced less sediments per hectare disturbance. The low value was estimated based on section 8.2.2.4. The CL units only have one value for the sediment production which is the high value
(3) Estimate the annual sediment yield for both RIL and CL units over 60 years using the method outlined in section 8.2.2.5
(4) Calculate the total sediment yield for the RIL and CL units by multiplying the area in each category of logging disturbance area by their respective sediment yield

(5) Calculate and apply the sediment delivery ratio to (4) above. The reduction in sediment delivered from forest site to the river/reservoir was calculated based on the difference in sediment yield per unit area between Nussbaum's plot and Douglas's catchment studies for logged forest; then make comparison between the calculated SDR value and to SDR values of similar catchments size elsewhere to validate the use of the calculated SDR for the economic analysis

(6) Estimate and apply the proportion of sediment from upstream that would be trapped at the Pangi hydro power plant. A 40 % trap efficiency was used in this study.

(7) Value the annual loss of hydroelectricity over 60 years on the basis of loss of storage at the pondage of the Pangi hydro power plant. The cost per hectare for RIL and CL units are obtained by dividing the total costs by the area logged

(8) Calculate the discounted streams of economic costs (over 60 years) using discount rates ranging from 2 to 10 % at 2 % intervals

8.3 Results

8.3.1 Source and extent of soil erosion

The extent of roads, log landings and skid trails in the RIL and CL units are presented in Table 8.1, RIL units had a lower proportion of area for the three categories of soil disturbance. The area of roads in RIL and CL were about the same per management unit. However, the differences between the RIL and CL units in the area of log landings (RIL= 0.67 ha; CL = 1.70 ha) and skid trails (RIL= 4.26 ha; CL = 21.02 ha) were the highest. These differences in area and soil bulk densities (high bulk densities mean low water infiltration rates, hence produce more surface runoff and erosion) have a major impact on the overall sediment production between treatments, in addition to the differences in the actual sedimentation rate per unit area from each of the disturbance types.

8.3.2 The ratio of sediment yield between Nussbaum's (1995) and Douglas *et. al.*'s studies (1990)

The results of Nussbaum's (1995) and Douglas *et. al*'s (1990) field studies of sediment yield and concentration associated with CL techniques are summarised in Tables 8.2 and 8.3. Nussbaum found that total sediment yields from on-site measurements of undisturbed forest and disturbed forest with original litter-cover (mean = 22 t km^{-2} yr^{-1}) were about 210 times less than skid trails with their topsoil removed (4610 t Km^{-2} yr^{-1}). The effect of litter-cover was evident where skid trails with churned litter produced half the sediment compared with skid trails without litter cover. The higher rate of sediment yield from skid trail plot with a 5° slope compared with a 15° slope was because the plot with a 5° slope was located at a junction between two skid trails where the bulldozer churned up

Table 8.1 Mean values of the extent of soil disturbance and bulk densities on roads, log landings and skid trails in RIL and CL units

Category of disturbance	Area (ha) of total logged area		Bulk density (g cm^{-3}) RIL or CL	Size (Ha)
	RIL	CL		
Road	4.35	6.48	1.8 - 2.0	n/a
Log landing	0.67	1.70	1.8 – 2.0	0.2 – 0.5
Skid trail	4.26	21.04	1.3 -1.6	n/a

Source: This study chapter 6, table 6.1(Data about the variability on the extent of disturbance between RIL and CL units are given in table 6.1

the soil while turning, resulting in a large amount of loose material on the skid surface which eroded during rain wash. The values reported for the litter-covered plots and on bare areas were within the range reported in other studies in various sites in Malaysia and elsewhere (Table 8.4). However, the lack of replication in Nussbaum's study implied that the results can only be interpreted with caution.

The sediment yield recorded at the outlet of catchments as reported in Douglas *et. al.*'s (1990) study exhibited a similar difference in sediment yield between undisturbed and disturbed treatments. The ratio of annual sediment yield from the logged catchment to that from a nearby undisturbed catchment changed from the order of 1:1 before logging to 1:52 after logging disturbance. According to that study, the first stage of commercial logging activity of road construction produced a peak sediment concentration following three major storms with an average 30 min intensity of 32 mm hr^{-1} of around 2,000 mg l^{-1} and lasting for 15 min. Following all three storms the peak sediment concentration in the logged catchment was three to eight times that in the nearby undisturbed catchment. The impact of logging within 37 m of the logging road triggered a peak sediment concentration of 12,947 mg l^{-1}, and levels of above 1,000 mg l^{-1} lasted for approximately 75 min. The build-up of fine material in the river bed indicated that in some storms more sediment was available for transport than the stream energy was able to carry. After log extraction operations, involving both tractor and high lead logging, sediment concentrations from the whole logged catchment were over 1,000 mg l^{-1} and persisted well over 75 min in most storms whether or not the rainfall was of short duration. Even a year after logging, sediment yield continued to rise especially after major storms (Douglas *et. al.*, 1990). Similar trends were noted in hydrological studies in other parts of Malaysia and one study reported that, following logging, sediment yield is high in the first year and decreases in the subsequent years (Baharuddin, 1992).

The sediment yield in the Ulu Segama Forest Reserve reported by Dougals *et. al.* (1990) was higher than estimates reported from the Berumbum forest reserve in Malaysia although lower than those found in the Ulu Langat and Air Hitam catchments in Malaysia (Table 8.4). For example, annual sedimentation yield recorded post-logging at Berumbun F.R., Negri Sembilan for unsupervised logging and supervised logging was more than 100 times lower than those reported in Sabah although a similar difference between the two forms of logging was found. The exceptionally high values in the Ulu Segama could be attributed to the geological characteristics of this area; the mudstones of the Kuamut Formation were much more erodible than the weathered granites and partly metamosphosed sediments of the areas in Peninsula Malaysia. In comparison to the

Table 8.4 Sediment concentration and annual sediment yield before and after logging disturbance at various sites in Malaysia

Location	Experimental Design	Size (ha)	Condition	Rainfall (mm)	Activity	Slope (degree)	Soil loss (Kg ha^{-1})	Sediment Conc (mg l^{-1}) Pre-log	Sediment Conc (mg l^{-1}) Post-log	Sediment yield (t km^{-2} y^{-1}) Pre-log	Sediment yield (t km^{-2} y^{-1}) Post-log
1 Ulu Segama F.R.	Catchment			2400-							
Sabah, Malaysia	a=W8S5	10,000	Unlogged	2900		5-45				31	n/a
	b=Stesyen Baru	5,600	Logged		a) Road construction		n/a	n/a	800-2,000	n/a	
					b) Extraction		n/a	n/a	1,000-12,947	n/a	
					c) Overall operation	5-45	16,000	2,000-2,600	1,000-5,000	n/a	1,600
2 Ulu Segama F.R	Runoff plot			2800	a) Unlogged	15	n/a	n/a	n/a	31	n/a
Sabah, Malaysia					b) Log landing	5-15	330,340	n/a	n/a	n/a	4,830
					c) Skid trails	15	155,520	n/a	n/a	n/a	2,510-4,830
					d) Extraction area	15 }	n/a	n/a	n/a	n/a	11-25
3 Tawau Hill Forest Sabah, Malaysia	Catchement		Logged	2600	Logging	35	385,000	n/a	n/a	n/a	n/a
4 Sipitang, Sabah	Catchment	3.4-18.2	Clear felled and logged	4460	Logging	27-57	2,530	n/a	n/a	9	39
5 Sabah, Malaysia	Catchment			2000-3000	Multiple landuse	n/a	n/a	n/a	n/a	n/a	200-700
6 Berumbun F.R.	Catchment			2549							
N Sembilan, Malaysia		a=12 9	Logged		a=conventional logging	13	n/a	4-386	3-844	14	27
		b=4.2	Control		b=control	10	n/a	4-217		19	n/a
		c=29.7	Logged		c=supervised logging	12	n/a	5-158	4-218	7	11
7 Sg Tekam F R.	Catchment			2508	Logging	14					
Pahang, Malaysia		a=36	Logged				n/a	n/a	21-112	n/a	20
		b=95	Logged				n/a	n/a	37-110	n/a	45
		c=57	Logged				n/a	n/a	28-29	n/a	37
8 Jenka Catchment	Catchment			2508	Logging	14	n/a	1-47	5-70	10	30
9 Ulu Langat	Catchment	a=309	Logged		Logging	11	n/a	n/a	1-1,669	n/a	1-1,970
Selangor, Malaysia		b=136	Logged (active)			14	n/a	n/a	4-7,688	n/a	4-10,530
10 Air Hitam F R.	Catchment	a=730	Logged (recent)		Logging	n/a	n/a	n/a	2-1,305	n/a	7-48,700
Selangor, Malaysia		b=470	Logged						1-292		13-4,800
11 Ulu Gombak F.R.	Runoff plot										
Selangor, Malaysia		a=574	Unlogged			n/a	n/a	2-388		n/a	n/a
		b=326	Logged (recent)			n/a	n/a		3-1132	n/a	n/a
		c=356	Logged			n/a	n/a		3-1585	n/a	n/a

References: 1.Douglas *et. al.,* 1990; 2.Nussbaum, 1995; 3. Liew, 1974; 4. Malmer, 1990; 5. Murtedza, 1990; 6, 7, 8, 9, 10 & 11 Baharuddin and Abdul Rahim, 1994 recently logged forests of the Ulu Langat and Air Hitam catchments the sediment yield reported for the Ulu Segama catchment was significantly lower, presumably due to different logging methods and geographical settings (Table 8.4).

In summary, the studies by Nussbaum (1995) and Douglas *et. al.* (1990) reported remarkably similar levels of sediment yield in undisturbed forest (about 31 t km^{-2} yr^{-1}) but produced contrasting results for disturbed forests using plot and catchment scale designs, respectively. Nussbaum estimated that 4,195 t km^{-2} yr^{-1} of sediment were produced from her erosion pin study; about 2.6 times higher than that reported by Douglas *et. al.* but the latter was within estimates reported by Kasran and Abdul Rahim for the Ulu Langat and Air Hitam studies in Malaysia (Table 8.4). Based on the sedimentation yield data of Nussbaum (1995) and Douglas *et. al.* (1990), the SDR for the Ulu Segama area was estimated to be 0.38 (Table 8.2 and 8.3). This ratio was calculated by taking the sediment yield reported in Douglas *et. al.*, (1,600 t km^{-2} yr^{-1}) and dividing by the mean sediment yield of Nussbaum's data (4,195 t km^{-2} yr^{-1}). This ratio was comparable with SDRs reported in Brooks (1982) for a case study in Northern Morocco. It also agrees with those of Hadley and Shown (1976) although the magnitude of the masses transported differed. A similar study in the Philippines reported a sediment delivery ratio of 40 % (Briones, 1985). On this basis, Nussbaum's sediment yield data (Table 8.2) were utilised for the analysis.

8.3.3 Sediment yield for RIL (high and low estimates)

From section 8.2.2.4, the difference between RIL and CL for the proportion of soil bladed averaged 50 % of total area logged (RIL = 50 %; CL = 87 %). For churned soils, the difference per area logged was 40 % (RIL = 11 %; CL = 50 %). These estimates represent the immediate post logging impacts (1-2 years). However, over the full 60 year rotation for which the analyses in this study are being conducted, the differences between the rate of erosion per area of bare soil eroded in RIL and CL is likely to be reduced once the soil vulnerable to erosion is removed from the surface to leave a more uniform compacted soil beneath, and as plants regenerate on these sites, tree roots regrow and a surface litter layer builds up. This rate of recovery is expected to be greater on skid trails than on the more compacted soils of log landings (Pinard *et. al.*, 1996). However, it has been assumed that the average difference in sedimentation rate per area of bare soil over the 60-year rotation remain unchanged between CL and RIL at 50% for log landings and 40% for skid trails.

8.3.4 Sediment yield at the reservoir

The estimated sediment yield from roads, log landings and skid trails for the RIL units at time t_0 for the low and high sediment yield were 317 and 394 t yr^{-1}, respectively

(Table 8.5). These estimates were based on total sediment yield generated from 9.28 ha or 7 % of the total 129 ha logged of RIL units. With a 15.2 % delivery ratio into the reservoir (38 % of the gross sediment discharged from these catchments and 40 % trap efficiency at the reservoir), total sediment yield accumulated downstream was 48 and 60 t yr^{-1} equivalent to 30 and 37 m^3 yr^{-1}, respectively (Table 8.5). The per logged hectare of RIL (129 ha) sediment yield would be 0.37 and 0.47 t yr^{-1}.

The CL units with a bigger area of roads, log landings and skid trails totalling 29 ha or 17 % of the total area of 175 ha, had sediment yield at t_0 of 1,149 t yr^{-1}, which was nearly three times the amount of the RIL units. This gave a trapped sediment yield at the reservoir of 175 t yr^{-1}, equivalent to 109 m^3 yr^{-1}. The sediment yield per hectare of CL would be 1.00 t yr^{-1}.

Working with the volume of sediment trapped in the reservoir at t_0, the annual sediment for the years following logging (up to 60 years) for both the RIL and CL units showed a gradual decline based on the results of the model used in this study (Figure 8.2). The projected sediment decline follows a straight line in both cases as they were plotted based on two given sedimentation yields, one at time t_0 and the other at t_{60} (Figure 8.3). There could be other possible trend lines depending on sediment flows between these two time points. In this study, the slopes of the lines for RIL (both high and low values) were more gradual than that found in CL (RIL_H = 0.25; RIL_L = 0.20; CL = 0.312). The low initial sediment value caused the more gradual slope in RIL. The difference in slope gradients means that the annual sedimentation yield for each treatment would differ.

At t_{60}, the annual volume of sediment trapped in the reservoir for the RIL_L, RIL_H and CL units was 18, 23 and 91 m^3 yr^{-1} (Appendix 8.1). The proportion of reduction in sediment yield from t_0 was 39 %, 40 % and 17 %, respectively due to the much faster recovery rates for RIL than in the case of CL. The total sediment yield (before reaching the reservoir) from the RIL units was 192 t yr^{-1} for low estimate, and 239 t yr^{-1} (Table 8.5: these estimates were calculated by multiplying the volume of sediment trapped in the reservoir by a factor of 10.524, representing the conversion rates from sediment volume to mass, and sediment delivery ratio). For the CL units, the total sediment yield was 955 tyr^{1}

Over 60 years, the total sediment trapped at the reservoir from RIL units for RIL_L and RIL_H was 1,450 and 1,805 t (Appendix 8.1). For CL units, the total sedimentation trapped was 6,077 t; about four times that of RIL units. The total trapped sediments over 60 years were 15,257 t for the RIL_L, 18,985 t for the RIL_H, and 63,087 t for the CL units.

Table 8.5 Estimates of sediment yield from RIL and CL units at time t_0 and t_{60} (The projected sediment yield for the 60-year rotation is given in Appendix 8.1)

	Road	Log Landing	Skid Trail	Total (t_0)	Total (t_{60})	Total (t_0-t_{60})*	Reference
1 Sediment contributing area (ha)							
a) RIL units (out of 129 ha)	4.35	0.67	4.26	9.28	9.28	9.28	Chapter 6 (Table 6.1)
b) CL units (out of 175 ha)	6.48	1.70	21.02	29.19	29.19	29.19	
2 Sediment yield ($t\ ha^{-1}\ y^{-1}$)							
a) RIL units - (i) High sediment	48.00	48.00	36.00	n/a	n/a	n/a	Nussbaum, 1995
(ii) Low sediment	48.00	24.00	21.60	n/a	n/a	n/a	This study (section 8.2.2.4)
b) CL units	48.00	48.00	36.00	n/a	n/a	n/a	Nussbaum, 1995
3 Total sediment yield ($t\ y^{-1}$) from							
a) RIL units - (i) High sediment	208.67	32.20	153.25	394.12	238.96	19221.56	
(ii) Low sediment	208.67	16.10	91.95	316.72	192.03	15446.70	
b) CL units	310.80	81.48	756.63	1,148.91	954.66	64037.91	
4 Sediment delivery ratio							
a) River/Site loss	0.38	0.38	0.38	0.38	0.38	0.38	This study (section 8.3.2)
b) Trapped in reservoir	0.40	0.40	0.40	0.40	0.40	0.40	Magrath and Arens, 1989
5 Total mass of sediment trapped in reservoir ($t\ y^{-1}$)							
a) RIL units - (i) High sediment	31.72	4.89	23.29	59.91	36	2,923	
(ii) Low sediment	31.72	2.45	13.98	48.14	29	2,349	
b) CL units	47.24	12.38	115.01	174.63	145	9,740	
6 Total volume of sediment yield at reservoir ($m^3\ y^{-1}$)							
a) RIL units - (i) High sediment	19.82	3.06	14.56	37.44	22.71	1,827	
(ii) Low sediment	19.82	1.53	8.74	30.09	18.25	1,468	
b) CL units	29.53	7.74	71.88	109.15	90.75	6,087	

Notes:

1 Calculated by multiplying the total area of RIL (230 ha) and CL (175 ha) units by item (2)

2 The values 48 come from Table 8.2 line 4; value 36 comes from Table 8.2 taking the average of line 5 and 6. High sediment (I.e. worst case) in RIL assumed no RIL-CL difference in sedimentation rate and low sediment (best case) assumed RIL-CL difference. Low sediment yield obtained by assuming a reduction of 50 % and 40 % for log landing and skid trail, respectively of high sediment yield in the RIL units

3 For t_0: item (1) x (2) but for t_{60} is multiplying item (6) with a factor of 10.52 adjust for the conversion factors in item 5 and 6 (This is because the projection for 60-year rotation was based on item 7)

4 SDR for river to site loss = 0.38 (Calculated by this study setion 8.3.3)
Sediment trapped ar reservoir (Brooks, 1987; Magrath and Arens, 1989)

5 Calculation: item (4) x (5a) x (5b) [(5a) x (5b) = 0.152]

6 Item (6)/1.6 This is a mass to volume conversion {Conversion factor: 1 m^3 = 1.6 t} Brooks, 1987

7 * The gives the total projected sediment yield (volume) for 60 years. The calculations is given in Appendix 8.1

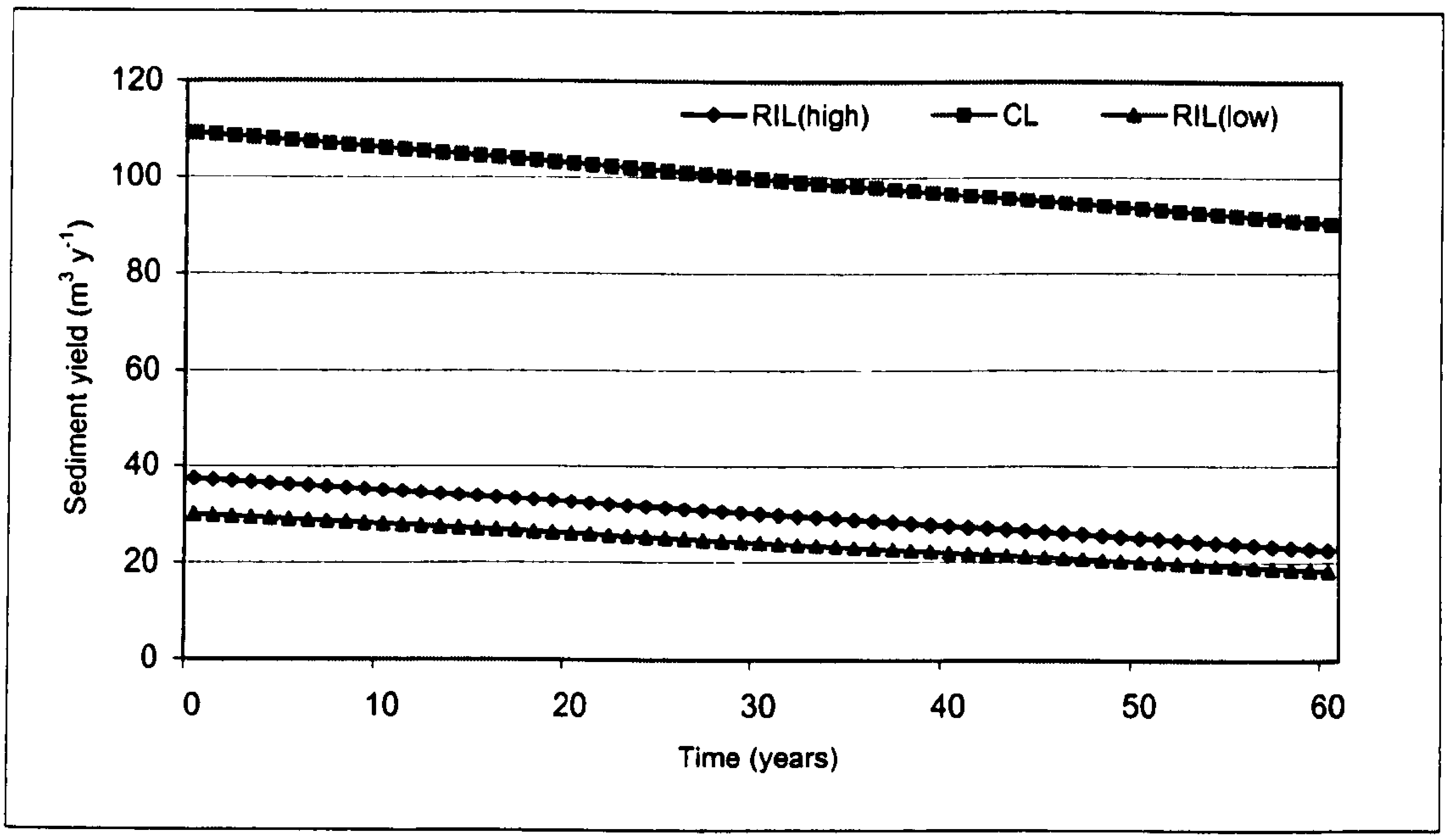


Figure 8.2 Projected sediment recovery curves for RIL and CL units over 60 years (data from Appendix 8.1)

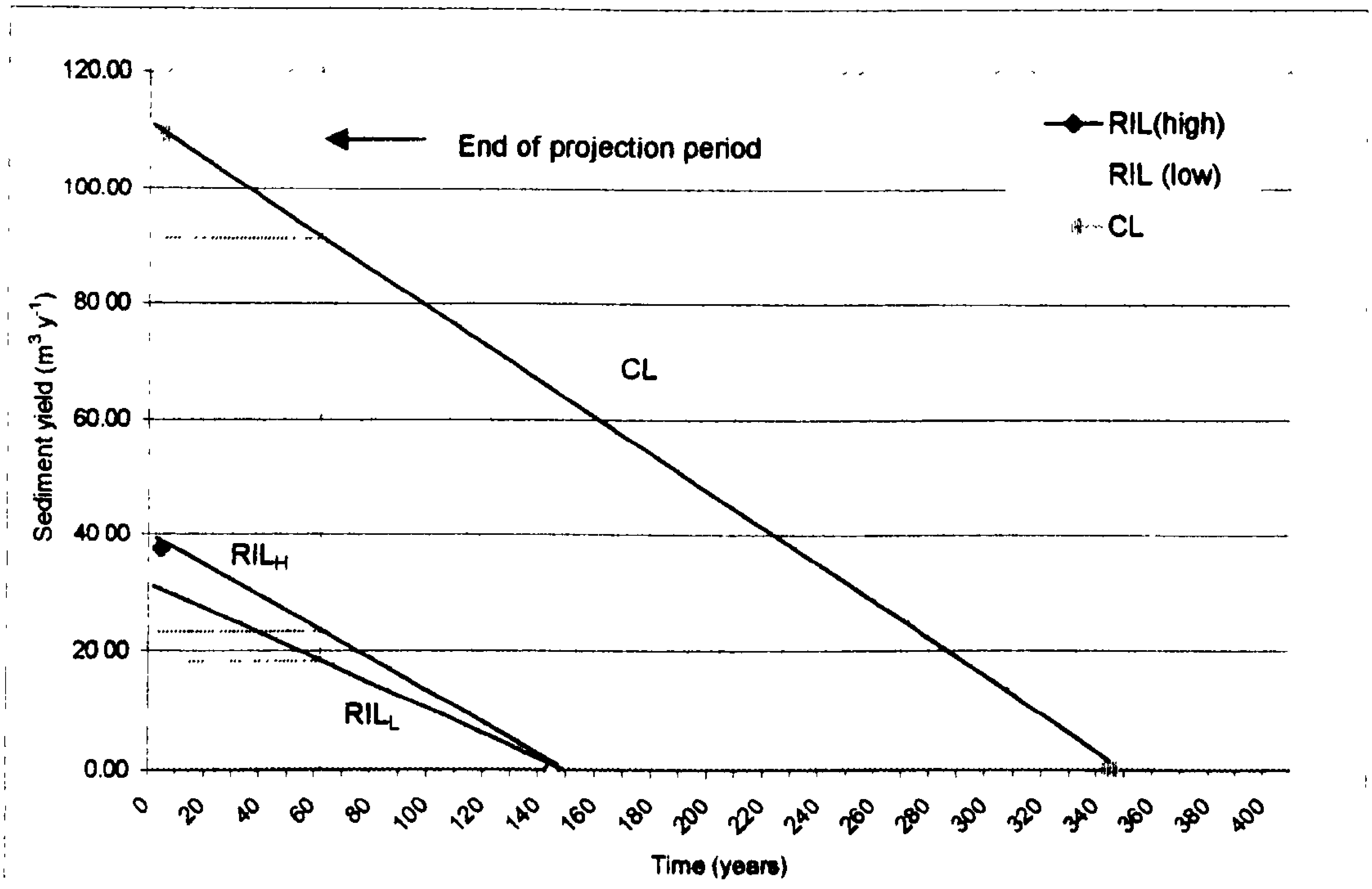


Figure 8.3 The time course of sedimentation. Annual sediment yield was estimated on the basis of the gradients between two known yields at t_0 and t_{60} (see examples below)

The gradients of the RIL and CL lines are calculated by:

$$RIL_H = \frac{x}{y} = \frac{37.44}{150} = 0.250$$

$$RIL_L = \frac{x}{y} = \frac{30.09}{150} = 0.201$$

$$CL = \frac{x}{y} = \frac{109.15}{350} = 0.312$$

Thus, the equations of the three lines are:

RIL_H	=	$Y = A - 0.250x$	where A = sediment yield at t_0
RIL_L	=	$Y = A - 0.201x$	(RIL_H = 37.44 RIL_L = 30.09 CL = 109.15)
CL	=	$Y = A - 0.312x$	x = year at which estimate is made

Examples: To calculate sediment yield ($m^3\ y^{-1}$) at year 20 for

a) RIL_H	=	37.44	-	0.250	x	20	=	32.45
b) RIL_L	=	30.09	-	0.201	x	20	=	26.08
c) CL	=	109.15	-	0.312		20	=	102.91

Table 8.6 Projected sediment yield data and economic costs of sedimentation over 60 years

A Catchment area

A.1	RIL	129 ha
A.2	CL	175 ha

B Cost of dredging sediment pond

B.1	Hiring of excavator and lorry	200 RM/hr
B.2	Excavator's load	1 m^3
B.3	Time to remove sediment	0.333 min/m^3

C Cost of forgone electricity for shutting down hydroelectric plant

C.1	Price of electricity	0.165 RMKWh
C.2	Station output	338720 MWh/yr
C.3	Operating days in a year	365 days
C.4	1 MWh equals	1000 KWh
C.5	Number of hours per day	24 hr

D Economic valuation

		Dredging		Hydroelectricity		Dredging + Hydroelectricity	
	Rate	RM	Per ha	RM	Per ha	RM	Per ha logged
RIL_H	0%	2003.19	15.53	63901.88	495.36	65905.08	510.89
	2%	1216.44	9.43	38804.58	300.81	40021.02	310.24
	4%	823.03	6.38	26254.81	203.53	27077.84	209.91
	6%	605.44	4.69	19313.49	149.72	19918.93	154.41
	8%	473.56	3.67	15106.50	117.10	15580.06	120.78
	10%	387.17	3.00	12350.59	95.74	12737.75	98.74
RIL_L	0%	1609.79	12.48	51352.42	398.08	52962.21	410.56
	2%	977.55	7.58	31183.88	241.74	32161.43	249.31
	4%	661.40	5.13	21098.72	163.56	21760.12	168.68
	6%	486.54	3.77	15520.59	120.31	16007.12	124.09
	8%	380.56	2.95	12139.79	94.11	12520.35	97.06
	10%	311.13	2.41	9925.10	76.94	10236.23	79.35
CL	0%	6656.47	38.04	212341.32	1213.38	218997.79	1251.42
	2%	3926.25	22.44	125247.29	715.70	129173.54	738.13
	4%	2594.47	14.83	82763.70	472.94	85358.17	487.76
	6%	1875.25	10.72	59820.59	341.83	61695.84	352.55
	8%	1448.46	8.28	46205.97	264.03	47654.43	272.31
	10%	1173.73	6.71	37441.90	213.95	38615.63	220.66

D Sample calculations for item (B) and (C)

D. 1 Sample calculation for item (B)

To calculate time/cost to remove sediment for first year if sediment load = 38 m^3,
Hours required to clear sediment
= 38 m^3 x 0.333/60 = 0.21 hr (13 min)
Cost to clear sediment
= 0.21 hr x RM200/hr = RM42

D.2 Sample calculation for item (C)

To calculate the cost of forgone electricity during shut-down for dredging
Power supply in a day (in KWh)
338,720 x 1000 KWh//365 days = 928,000 KWh
Power supply for 1 hour (KWh)
928,000 KWh/24 = 38,667
Loss of electricity for 0.21 hrs
= 38,667 KWh x 0.21
= 8,120 KWh
Opportunity cost of shut-down for 0.21 hrs
= 8,120 KWh x 0.165 RM/KWh
= RM1,339

8.3.5 Economic valuation

8.3.5.1 Dredging costs

Over a period of 60 years, the total costs of dredging sedimentation at the pondage of the Pangi hydro power plant using RIL_L and RIL_H were estimated as RM1,609 and RM2,003, respectively. These estimates were based on a total sediment trapped of 1,450 m^3 and 1,8045 m^3 per management unit over 8 to 10 hours of dredging (Table 8.6).

With CL, the dredging costs was RM6,657 over the 60 years, and was much higher than the RIL cost. The higher dredging cost for CL was associated with higher amount of sediment production, hence longer dredging hours.

The total undiscounted dredging cost per hectare for the three scenarios (RIL_H, RIL_L and CL) were RM16 ha^{-1}, RM12 ha^{-1} and RM38 ha^{-1}, respectively.

8.3.5.2 Cost of hydroelectricity

The opportunity costs of forgone hydroelectricity if the power plant had to be shut down for dredging works was substantial compared with dredging costs. With RIL, the RIL_H and RIL_L estimates were RM63,901 and RM51,352, respectively. The per hectare costs were RM495 and RM398, respectively. With CL, the opportunity cost of forgone hydroelectricity was even higher – at RM 212,341 or RM1,213 ha^{-1} over 60 years.

8.3.5.3 Total cost of dredging and hydroelectricity

The economic cost of sedimentation was dominated by the loss of hydroelectricity. Using RIL to harvest timber could potentially reduce the opportunity cost of hydroelectricity by about three times (RIL_H = 495 ha^{-1}; RIL_L = RM398 ha^{-1}; CL = RM1,213 ha^{-1}; Table 8.6). The potential net economic cost saving would be between RM718 ha^{-1} and RM815 ha^{-1} by adopting RIL (Table 8.6). The primary factor causing this difference related to differences in total sediment production between RIL and CL.

If a 2 % discount rate was adopted, the economic loss per hectare would reduce to approximately 39 % for RIL and 41 % for CL compared with the undiscounted costs (Table 8.6). With higher discount rates, the economic loss would decline further; by about 70 % at 6 % discount rate, and 81 % at 10 % discount rate.

8.4 Discussion

Logging in the Ulu Segama Forest Reserve produced sediment that would end up in the river system. The major source of sediment associated with selective logging is from roads, log landings and skid trails.

If sediment production were confined to logging disturbance in log landings, skid trails and roads, total sediment production over 60 years from the 129 ha catchment logged with RIL techniques would yield between 15,447 t and 19,222 t (Table 8.5). With conventional logging, the projected sediment load from the 175 ha of forest would produce approximately 64,038 t. The annual sediment production for RIL_L, RIL_H and CL over 60 years were 257, 320 and 1,067 t yr^{-1}, and the per hectare annual sediment production were 2-2.5.0 t ha^{-1} yr^{-1} and 6 t ha^{-1} yr^{-1}, respectively.

The projected annual sediment yields from this study were within the range reported in other studies for forest catchments in Malaysia (e.g. Baharuddin and Abdul Rahim, 1994; Table 8.4). However, it must be cautioned that hydrological studies differed in terms of site conditions, rainfall volume and intensity, logging techniques, methods of analysis, etc. Consequently, the comparison must be viewed as means to indicate orders of magnitude.

On a per hectare basis, the total sediment yield from the RIL units was comparable with the estimates of 1-2 t ha^{-1} yr^{-1} reported by Mohd Shahwahid *et. al.* (1998) for a case study using supervised logging.

This study found that the total sediment trapped at the reservoir from the 129 ha and 175 ha catchment units was 2,320 t for RIL_H, 2,887 t for RIL_L and 9,595 t for CL over 60 years. This is equivalent to a per hectare estimates of 18 t, 22 t and 74 t of sediments over 60 years or annually 0.30, 0.37 and 0.91 t ha^{-1} yr^{-1}. These estimates were far below the estimates of 5 t ha^{-1} yr^{-1} reported by Mohd Shahwahid *et. al.*'s (1998) study.

Studies of sediment yield associated with reservoirs have been reported elsewhere but for different land use, duration of analysis, and environments. The comparisons are also not meaningful due to difficulty in converting estimates to a per hectare basis. Brooks (1982), for example, reported sediment yield at a reservoir of 3.8 x 10^6 m^3 yr^{-1} from mining operations in the Loukkos Basin in Northern Morocco where 42 % of the 182,000 ha watershed was agricultural land, 21 % was forested and 28 % was range land. Briones (1985) reported sediment yields of 3,200 – 6,500 m^3 km^{-2} yr^{-1} from the lower Agno River watershed in the Philippines which received average annual rainfall of 3,629 mm. About 40 % of the 39,304 ha watershed was forested, and 50 % was grassland. In Nepal, the Kulekhani reservoir was reported to experience sediment level of approximately 3,000-4,000 t km^{-2} yr^{-1} from upland watershed forest removal, grazing and cultivation as well as road construction and riverbank erosion (Brooks, 1987).

The significance of downstream sedimentation is apparent when it is valued against the opportunity cost of hydroelectricity and the costs of dredging. For this case study, the forgone opportunity cost was dominated by the loss in hydroelectricity. In using RIL to harvest timber, the off-site costs associated with sedimentation were RM461 ha^{-1} (average of high and low values). This was about half the estimate obtained by Mohd Shahwahid *et. al.* (1998) of RM724 ha^{-1} split between the cost forgone hydro power generation and dredging costs. The significant difference in the dredging costs between this study and that of Mohd Shahwahid *et. al's* could be due to differences in the location of the sediment intake ponds and sediment yield.

By adopting RIL, the net economic benefit (or saving) over CL would be approximately RM153,093 for 60 years. The net benefit per hectare was RM741, and represents part of the total costs that the timber industry usually externalize i.e. they do not include these costs as part of their operating cost rather passing them to the hydropower plant. The per hectare logged total external costs associated with RIL and CL techniques were RM511 for RIL_H, RM411 for RIL_L and RM1,251.

At higher discount rates, the costs of sedimentation would reduce dramatically compared with no discounting. Discounting tends to reduce the long term economic costs to insignificance. This also implies that the economic tradeoff from switching to reduced impact logging from conventional logging on the basis of sedimentation reduction may not be strong enough to justify the switch.

The results presented in this study, however, were based on a number of assumptions ranging from the physical parameters of sedimentation to the financial parameters. While every effort was made to reduce errors in these, the fact remains that there were critical gaps in knowledge surrounding two principal parameters; 1) values of sediment yield at source and downstream, 2) trap efficiency at the reservoir, and 3) cost of time of dredging.

The principal problems encountered in this study lay in that the precise relationships between hillslope erosion, erosion control practices and sedimentation was poorly known due to lack of data on rates of surface, gully or mass soil movement erosion (Gregerson *et. al.*, 1987). This problem was compounded by the lack of knowledge of the impact of factors such as the amount and intensity of rain received, slope angle, erodibility of soil, effect of canopy texture on raindrop sizes, soil hydrology, in-channel erosion and the techniques of log extraction procedures (Brooks and Spencer, 1995).

One major assumption used in this study was that the long-term (over 60 years) sediment decline was based on a straight-line trend. This may be an over simplification of the situation, but some assumption is necessary in order to draw general implications about the long-term economic cost of sedimentation due to logging. This is a technical problem which could be improved when more data are available on erosion processes.

This study also assumed that the effect of position of logging impacts within the catchment (i.e. on up slope or lower slope or near water courses) did not differ between treatments. This omission would most probably overestimate the sediment yield from the RIL units.

The trap efficiency at the reservoir depended on a host of factors such as the design of the reservoir, its operation, machines used and river flow. However, a 40 % trap efficiency (versus 90 % in most cases) adopted in this study was probably within acceptable estimates given that the river water had high flow rates that kept more silt in suspension and thus led to a lower trap efficiency than reservoirs receiving lower river flow rates and with longer storage periods.

With these caveats in mind, the economic costs of sedimentation presented in this chapter cannot be considered comprehensive. It does, however, highlight the desirability of incorporating watershed management practices in logging operations to reduce the off-site adverse effects of sedimentation. In doing so, the external costs of sedimentation would be internalised instead of being pass to the hydropower plant as in this case study.

8.5 Conclusion

The adoption of RIL would reduce the environmental externality of sedimentation downstream through careful timber felling and extraction operations. The economic significance of this reduction means that the generation of hydro-electricity would be less costly. Within the assumptions used in the economic analysis, this study found that the potential costs of forgone electricity due to sedimentation could be halved if RIL instead of CL was adopted to harvest timber. However, the results must be accepted as having a wide confidence interval. There are severe limits to the availability of reliable data on the rate at which soil erosion takes place in the forest, and a lack of understanding of physical and behavioural processes of sediments on land and in water, as well as of the quantitative sediment delivery relationship from terrestrial and stream channels. Accepting these weaknesses, this case study has illustrated a logically consistent framework in which the economic significance of soil erosion can be assessed.

Chapter 9: Wildlife

9.1 Introduction

The aim of this chapter is to evaluate and compare the impacts of RIL and CL techniques on the economic value of wildlife[1]. There are three justifications for including wildlife as a non-timber benefit in this study and the first is its importance as an economic resource (Aiken and Leigh, 1985). The greatest economic value of wildlife in Sabah is for its meat, skins, hides, decorations and medicine value (the use values), and total revenue from wildlife products in 1988 amounted to about RM6 million (Statistics Department of Sabah). This reported value probably represents only a part of the total worth for wildlife products from Sabah because wildlife products such as meat, hides etc. are rarely sold in the market, but rather are consumed as food and for personal use (Stuebing *et. al.*, 1993). In recent years, the non-consumptive use value of wildlife is becoming apparent in Sabah, particularly, in the eco-tourism sector.

The second justification for including wildlife as a component of the overall assessment of RIL and CL techniques is that logging activities are known to have a major effect on wildlife species through the impact on their habitat. Selective logging in Malaysia has been considered as one of the main agents threatening wildlife through temporary disruption or permanent habitat change (Payne, 1982). The artificial canopy gaps created by selective logging could affect animal species that depend on aerial pathways. The loss of a continuous canopy pathway forces animals that browse from canopy tops (e.g. orang-utans) to climb down from the tree in search for food; this makes them more vulnerable to hunting. Some infant mammals may die from falling when adults try to leap across wide canopy gaps (Shelton, 1987). Logging damage to the residual trees can be drastic with up to 40 % of the vegetation being destroyed (Fox, 1968); trees destroyed might well be a food source for wildlife (Wilson and Johns, 1982). The sudden changes in microclimate conditions from forest openings could have negative impacts on wildlife feeding habits (Zakaria, 1990; Thiollay, 1992; Heydon and Abdul Hamid, 1994) and ranging patterns and breeding success (Wong, 1985; Johns, 1988a; Bierregaard and Lovejoy, 1989). Roads which provide logging access are used by hunters and poachers to gain access to otherwise inaccessible areas (Caldecott, 1990). Therefore, changes in the forest structure, food availability, microclimatic or other environmental conditions following logging can result in changes in the abundance of individual species affecting their economic value.

[1] The term wildlife is used here for a specific group of wild animals excluding the plant community (namely the ungulates as justified in section 9.2.2.3). This definition restricting wildlife to wild animals has historical precedents and is still being used today (e.g. Hickey, 1974; Abidin *et. al.*, 1991; Stuebing *et. al.*, 1993) although wildlife management embraces the ecology of all vertebrates and their plant and animal associates (see Hunter, 1990 for a discussion of the term).

The adverse effects of logging can be minimised with better harvesting practices such as RIL which reduce the incidental damage and the extent of openings for roads, skid trails and log landings. Mechanized logging carried out properly could sustain the food resources and support wildlife population. However, in order to compete for the attention of decision-makers to persuade them to consider adopting improved harvesting practices, it is useful to demonstrate the value of RIL in economic term. Such a strategy in using economic justifications to influence decision-making is not uncommon as there are ample examples of those who have succeeded in using the same reasoning to support alternative use of resources (McNeely *et al.*, 1990). This is the third reason for considering wildlife benefit in relation to logging impacts in this study.

The chapter begins with a brief description of the study sites introducing the flora and mammalian fauna of the Ulu Segama Forest Reserve. The effects of logging on wildlife in the study area are reviewed which provides the basis for selecting the wildlife target groups and the source of data for the economic analysis. The use of secondary wildlife data for the economic study is justified. The techniques employed to estimate wildlife density associated with RIL techniques are described based on a relationship between logging intensity and wildlife density. From this, the animal density was projected to 60 years which is the main focus in section 9.2.2.5. The chapter also provides a brief review of valuation techniques and the choice of technique for valuing wildlife benefit in this study. In the final part of the chapter, the comparative wildlife economic values between the RIL and CL areas are discussed and appropriate management implications drawn.

9.2 Materials and methods

9.2.1 Study sites

The study is located within the Ulu Segama Forest Reserve of the Sabah Foundation forest concession but outside the RIL and CL units described in Chapter 2. The reasons for not having the study inside the RIL and CL units were time and resource constraints and the full justifications are given in section 9.2.2.1. The geographical location, geology, climatic data and vegetation of the study area have been described in Chapter 2. The following briefly describes its flora and fauna populations.

Within the Ulu Segama Forest Reserve, primary and logged forests exist with the latter occurring in a mosaic of different ages depending on when they were logged. The forest composition in the primary and logged forests is dominated by the families Euphorbiaceae, Dipterocarpaceae, Meliaceae and Lauraceae. In the primary forest, there are more trees and bigger size (in terms of DBH, crown area and tree height) than the logged forest (Zakaria, 1993; Norhayati *et. al.,*1998) because trees in primary forest are still intact whereas in logged forest trees over 60 cm DBH have been selectively harvested and smaller trees destroyed during the process of logging.

The mammalian fauna of the Ulu Segama Forest Reserve that have been sighted in primary and logged forests include notably: the Asian elephant (*Elephas maximus*), Sumatran rhinoceros (*Dicerorhinus sumatrensis*), banteng (*Bos javanicus*), sambar deer (e.g. *Cervus unicolor*), Malayan sun bear (*Helarctos* spp.) and clouded leopard (*Neofelis nebulosa*) (Davies and Payne, 1982; Payne *et. al.,* 1985).

There are also relatively high densities of other mammals: the bearded pig (*Sus barbatus*) is common while the barking deer (*Muntiacus* spp.) and mouse deer (*Tragulus* spp.) are also frequently seen. Tree shrews (*Tupaia* spp.) and other small mammals form a diverse constituent of the fauna.

Of the arboreal mammals, all 10 species of primate found in eastern Sabah are found in the Ulu Segama Forest Reserve, including the orang-utan (*Pongo pygamaeus*), the Borneon gibbon (*Hylobates muelleri*), the red langur (*Presbytis rubicunda*) and macaque (*Macaca* spp.). Nocturnal arboreal mammals such as flying squirrels (e.g. *Petaurista elegans*) are also found. The avifauna population include the Argus pheasant (*Argusianus argus*), owls (*Otus* spp.), eagles (e.g. *Spizaetus nanus*) and eight species of hornbill (e.g. *Buceros rhinoceros*) (Smithies, 1960).

Many of the mammal and bird species are frugivorous, and the distribution of fruit within the forest is a strong influence on their existence (Johns, 1992). Some, e.g. *Pongo pygmaeius, Hylobates muyelleri* and other primates, respond to the irregular nature of fruiting events by migrating.

Other animals range widely through the forest, seeking out food-rich environments as and when they occur. Hornbills cover vast areas of forest in search of fruit. The bearded pig is well known for its migration events and large herbivores such as the Asian elephant roam in herds (Davies and Payne, 1982).

9.2.2 Wildlife data

9.2.2.1 Primary versus secondary data

The wildlife data for this economic analysis are taken from secondary sources based on research projects conducted in primary and logged forests within the Ulu Segama Forest Reserve. This option was pursued after an attempt to continue with the wildlife survey initiated in 1994 within Parcel A failed due to access being prevented by collapsed bridges and culverts. The justifications for using secondary data for this economic study are as follows.

Firstly, most studies investigating mobile animals and birds encounter *pure* or *bias* effects (Lescourret and Genard, 1994). *Pure* effects are caused by the impact of spatial features of the landscape, e.g. patch size created by logging, on demographic processes. *Bias* effects are caused by habitat variation (altitude and vegetation structure) associated with fragmentation. Pure and bias effects expose some critical issues for the present economic valuation of mobile animals. For example, the size of the RIL (and CL) units may be small enough that the animals can easily move out of them into adjacent areas during logging. This could give an impression that forests which have already been logged contain a higher density of certain species, which in fact, are only a transient response of wildlife to logging disturbance. Another relevant issue is the carrying capacity for the species of the surrounding unlogged areas, and whether they can absorb animals displaced from the logged areas without any increase in mortality, or if they are already saturated. This may not be a straight-forward matter, and the answer may depend on whether the animals can return to the logged areas sufficiently quickly before mortality rates rise far. Unfortunately, the science behind these issues, e.g. animal behaviour, is complex and not well understood (Healey *pers. comm.*; Johns, 1997).

Secondly, changes in the wildlife community due to disturbance might not be detected until after several years (Marsh and Wilson, 1981). As such, a survey carried out immediately following logging in the study area (RIL and CL units) might not give accurate results. Most of the wildlife studies within the Ulu Segama Forest Reserve were over time-scales longer than could be afforded for this study (due to time and budget constraints).

Thirdly, the scope of the forest inventory for the RIL and CL units was restricted to timber species and did not provide detailed identification of fruit/food species that could be used by wildlife. It is essential to consider the food resource when investigating wildlife response to disturbance because the abundance of certain wildlife co-varies with the abundance of fruit trees (Johns, 1988a). A re-visit to the inventory plots was constrained by access due to collapsed bridges and culverts, lack of human resources, and budget constraints. As such, this study utilised secondary data sources for the economic analysis.

9.2.2.2 Logging effects on wildlife

Studies on the effects of logging on mammals and birds have been carried out in the Ulu Segama Forest Reserve and are summarised in Table 9.1. For primates, Johns (1992) compared their population density between primary, six and 12 years old forest and found that there were differences between the responses of the different species. The population density of the orang-utan (*Pongo pygmaeus*) was the same between the primary and six as well as 12 years old logged forests. However, the population density of gibbons (*Hylobates* spp.) in the six years old logged forest of 8 animals km^{-2} was higher than in primary and a 12 years old forests at 5 and 4 animals km^{-2}, respectively. For langurs (*Presbytis* spp.), their population densities in the primary forest of 14 animals km^{-2} was higher than the six and 12 years old logged forests at 10 and 9 animals km^{-2}, respectively. The population density of the macaques (*Macaca nemestrina*) in the primary forest of 16 animals km^{-2} was higher than the six years old forest (10 animals km^{2}) but was dramatically lower compared to the 12 years old logged forest (24 animals km^{-2}). Based on these findings, Johns (1992) concluded that primates generally adapted well to logging disturbance with some species adversely affected by the severity of disturbance due to the patchy distribution of food resources in logged forests.

For birds, Johns (1988a) reported that of the 223 species found in primary forest, 96 percent were also recorded in logged forests and several new additions have subsequently been observed in logged forest by Lambert (1992). Generally, reduction in abundance was found among terrestrial species and understorey foliage gleaning and fly-catching species following logging (Table 9.1). There was no significant change in bird species abundance among the generalist frugivore/insectivores and bird species that use the upper levels of the canopy; this suggested that selective logging still leaves enough canopy food source trees for these bird species (Johns, 1988a). Zakaria (1990) found that the observed density of birds and mammals in a one-year old logged forest was higher than primary forest and attributed this trend to two reasons; (1) logging debris in logged forest limited the movement of terrestrial birds and mammals, and (2) there were fewer fruiting trees in logged than in primary forest: consequently foraging animals were more concentrated around these trees rather than dispersed as would be the case in primary forest.

Table 9.1 Results of wildlife surveys conducted in primary and logged forests in the Ulu Segama Forest Reserve, Sabah, Malaysia

	Body weight (kg)	Primary Forest	Conventionally logged forest (years after logging)					Reference
			2	5	6	8	12	
A Primates density (individuals km^{-2})								
1 Orang-utan *(Pongo pygmaeus)*	50-100	0.3	n/a	n/a	0.7	n/a	1.1	Johns, 1992
2 Borneon gibbon (*Hylobates muelleri)*	5.0-6.4	5.3	n/a	n/a	7.8	n/a	4.1	
3 Red langur (*Presbytis rubicunda)*	5.5-7.0	13.6	n/a	n/a	9.8	n/a	8.8	
4 Flying squirrel *(Petaurillus hosei)*	4.7-4.8	2.0	n/a	n/a	3.6	n/a	3.9	
5 Pig-tailed macaque (*Macaca nemestrina)*	4.0-6.0	15.8	n/a	n/a	10.0	n/a	24.0	
B Ungulate densities (individuals km^{-2})								
1 Mousedeer (*Trangulus spp*.)								Heydon and Abdul Hamid, 1994
Lesser mousedeer (*T. javanicus)*	1.5-2.5	28	11	9	n/a	n/a	15	
Greater mousedeer *(T. napu)*	3.5-5.2	53	4	2	n/a	n/a	13	
2 Barking deer (*Muntiacus spp.*)	15-20	6	4	4	n/a	n/a	4	
3 Sambar deer (*Cervus unicolor*)	80-150	1	2	2	n/a	n/a	n/a	
4 Western tarsier (*Tarsius bancanus)*	0.08-0.14	15	8	n/a	n/a	n/a	n/a	
C Bearded pig (*Sus barbatus*)	60-100	70	n/a	n/a	n/a	n/a	70	Norhayati, 1998
D Birds abundance (individuals)								
1 Terrestrial insectivore		78	n/a	n/a	n/a	76	n/a	Lambert, 1992 See note 1
2 Arboreal foliage gleaning insectivore		74	n/a	n/a	n/a	78	n/a	
3 Understorey specialists		44	n/a	n/a	n/a	57	n/a	
4 Bark gleaning insectivore/woodpecker		3	n/a	n/a	n/a	6	n/a	
5 Sallying insectivore		41	n/a	n/a	n/a	15	n/a	
6 Sallying substrate gleaning insectivore		9	n/a	n/a	n/a	2	n/a	
7 Arboreal foliage gleaning insectivore/frugivore		83	n/a	n/a	n/a	110	n/a	
8 Nectarivore/insectivore		31	n/a	n/a	n/a	76	n/a	
9 Nectarivore/insectivore/frugivore		19	n/a	n/a	n/a	30	n/a	
10 Terrestrial frugivore/insectivore		6	n/a	n/a	n/a	5	n/a	
11 Arboreal frgivore		9	n/a	n/a	n/a	1	n/a	
Total no. of birds		397				456		

Note

1 Birds' presence was recorded to species in the field but they were subsequently classifed to trophic levels or guilds to investigate their feeding behaviour

With small mammals, Heydon and Abdul Hamid (1994) investigated the impact of selective logging on ungulates in two years old, five years old and 12 years old logged forests and compared them to primary forest. They found that the density of mouse deer (*Tragulus* spp.) was substantially lower in selectively logged forests compared with primary forest, although there was an increased in density in 12 years old logged forest compared to a five years old logged forest. The density of barking deer (*Muntiacus* spp.) was approximately the same in primary and logged forests. Sambar deer (*Cervus* spp.) increased in abundance following selective logging as evident in two years old logged forest. There was a decline in sambar deer sighting rate in 12 years old logged forest which suggested that selective logging encouraged only a transient increase in deer density within the Ulu Segama Forest Reserve (Heydon and Abdul Hamid, 1994). All three animal species responded differently to the effects of logging; their population density and abundance have strong correlations with changes in food resource. This hypothesis is being investigated further with a recent study investigating the mammalian frugivores' response to changes in food resource due the logging effects in the Ulu Segama Forest Reserve (Norhayati, 1988). This study is still in the data collection phase and preliminary findings about the animal density and plant community in primary and logged forests have been reported and agree with the earlier studies (Norhayati, 1988).

Similar studies of the effects of logging on wildlife had been carried out elsewhere in tropical forests formations but they differed in a number of ways which do not permit direct comparisons. The factors that made direct comparisons difficult are the different composition of wildlife and vegetation communities being surveyed, and the geographic scale, local intensity, frequency, and methods of timber harvesting. Other confounding factors include the proximity and the extent of unlogged forest refugia, rate of hunting, number of years after logging and the inventory methods (Frumhoff, 1995).

Nevertheless, Shelton (1985) drawing from various studies in Peninsula Malaysia reported that the Sumatran rhinoceros, elephants, and honey bear were little affected by logging disturbance because they were able to take refuge in adjacent undisturbed forests during logging periods and returned to the sites after logging for new food sources.

Among primates, gibbons were less affected by logging compared with orang-utans, leaf monkeys and macaques because gibbons were fiercely territorial and hung-on to whatever remained of their home (Shelton, 1985). Marsh and Wilson (1981) found that the drop in gibbon populations in logged forest was more likely to be due to loss of aerial pathways, resulting in increased juvenile mortality from falls when their mothers leapt across wide canopy gaps. Leaf monkeys and macaques, being less territorial, could move freely and therefore showed an early decrease but recovered rapidly within two or three years after logging. Loss of cover and fruit trees is the main factor that discourages orang-utans from returning quickly to the logged forest.

An overview of logging impacts on birds in Peninsula Malaysia indicated that the species which were most affected by selective logging were understorey birds, such as babblers, pittas and the small forest kingfishers that are found in Malaysia (Johns, 1983). They were more affected by loss of cover and microclimatic changes than by reduction in insect food. Birds, however, recolonized logged forests in a relatively short time. A study conducted in the Pasoh Forest Reserve, Malaysia, found that out of the 83 species netted in the primary forest, all but three were also netted in the 25 years old logged forest (Wells, 1987), Another study in the Tekam Forest Reserve, Malaysia, showed a similar trend where only five of 193 species in primary forest were missing from logged forests (Johns, 1992). Hornbills, however, suffered from loss of large fruit and cavity-bearing trees needed for nesting (Kemp and Kemp, 1974).

Similar findings of birds' response to selective logging have been reported for a Guinean rain forest where low and mid-understorey bird communities declined while upper canopy bird species were unaffected by logging (Thiollay, 1992). This study also found that bird communities characteristic of large gaps had increased. The change in bird abundance after logging is correlated with a change in vegetation structure, and also changes in predation pressure from a reduction of the foraging space; from a decrease or shift of food resources; and from a response to the proximity of disturbances.

Most amphibians were affected by desiccation through the opening of the canopy but reptiles (e.g. snakes, lizards) and tortoises were better adapted to dry environments and therefore able to survive in logged forests (Shelton, 1985).

In summary, logging can cause a shift in the relative abundance of different animal species, favouring some disturbance-benefitting species over those sensitive to disturbance. The abundance of certain primates may co-vary with the abundance of particular fruit trees, and if these are eliminated by logging then the primate is also eliminated, if it is unable to find an alternative source of food. Terrestrial insectivores are often adversely affected by logging which reduces available insect resources through a combination of microclimatic and physical environmental effects. On the other hand, fruigivores and nectarivores (birds) are likely to be adaptable to logging impacts because they are able to shift diets to changed conditions in logged forests (Johns, 1997).

9.2.2.3 Selection of wildlife target group

From the review given above, it can be generalised that the two most important attributes which studies suggest control sensitivity to logging disturbance are the food resource and the mobility of the wildlife species. For the former, there is a direct correlation between the response of wildlife species and changes in their food resource associated with selective logging as shown in the studies of Thiollay (1992) and Heydon and Abdul Hamid (1994). For mobility, it is generally believed that large vertebrates such as the primates or hornbills are less affected by logging disturbance because they are able to move quickly to seek refuge in areas adjacent to disturbed areas (Johns, 1988b). Small species, on the other hand, are more likely to suffer severe population reduction, as most are less mobile. For the purpose of this analysis, the species choice would be a number of species which have a range of food source types and a range of size and thus mobility. As a third selection criterion, the wildlife target group should also have considerable value as an economic resource. This criterion facilitates the assigning of monetary value to the wildlife target group.

Based on these attributes and the wildlife studies conducted in the Ulu Segama Forest Reserve, primates are not good indicator species of logging effects because they take a long time to respond to environmental change (Johns, 1988b). Most tropical birds are also indifferent to logging disturbance since they are able to recolonize successfully even under intensive felling operations (Dranzoa and Johns, 1991). This leaves only the ungulates as relevant to this study because they have a broad diversity of diets. This suggests that they would be represented in both primary and logged forests removing a possible bias effect of logging due to its direct impact rather than the inability of animals to move (due to size). The ungulates namely, the mouse deer, barking deer, sambar deer and pig in this study area) are also the preferred target group because they have considerable value as a food source and, therefore, potential as an economic resource (Heydon and Abdul Hamid, 1994).

9.2.2.4 Source of wildlife data in conventional logged area

The effects of CL on ungulates in the Ulu Segama Forest Reserve have been studied by Heydon and Abdul Hamid (1994) and Norhayati *et. al.* (1998), and their data are utilised in this study.

Heydon and Abdul Hamid's (1994) study was aimed at investigating the impact of selective logging on ungulate abundance and the environmental factors that best explain the variation in ungulate behaviour and abundance. The survey areas were located in two primary forest sites and in logged forest of two years old (1991), five years old (1988) and 12 years old (1981). The primary forests study sites are located in the western portion of the Danum Valley conservation area (total conservation area = 44,000 ha). The logged forests were in logging coupes 1981 (3,642 ha), 1988 (3,200 ha) and 1991 (3,000 ha), and together they totalled approximately 10,000 ha. The Segama river formed a divide between the primary and logged forests study sites. Survey areas exhibited a comparable undulating topography, dissected by numerous streams. Timber extraction levels in the logged forest were similar, averaging 78 ± 7 m^3 ha^{-1}, which is within the range reported for RIL and CL units. The study focused on two mouse deer species (*Tragulus javanicus* and *T. napu*), two barking deer species (*Muntiacus muntja and M. atherodes*) and the sambar deer (*Cervus unicolor*). Two transects following either north-south or east-west directions were used in each forest type to survey ungulates density. Transects were between 2 and 3 km in length. Ungulate densities were estimated using line-transect surveying by direct observation. Animals were located at night by their reflected eye-shine using spotlights. Surveys were carried out on foot by two observers using spotlights. Each survey commenced at 1900 hr with observers travelling at between 500-700 m hr^{-1}. Transects were surveyed at monthly intervals over a five month period between August and December 1993. When ungulates were sighted, the species, number of individuals, sex, age, activity, location along transect and perpendicular distance from the transect line were recorded. A vegetation survey was also carried out by assessing the dominant vegetation type along the transect at 25 m intervals. To provide information on the effects of logging on tree species diversity and density of plants producing edible fruit, botanical plots were established in a 12-year old logged forest and in primary forest. These plots consisted of 1000 x 20 m strip-transects, subdivided into five 200 m (0.4 ha) sections. All trees greater then 10 cm DBH were identified. Fig tree abundance was also enumerated in view of its importance as a keystone food resource for many tropical vertebrates.

As a supplement to Heydon and Abdul Hamid's work, Norhayati *et. al.*'s (1998) study provides data for the bearded pigs (*Sus babatus*) which is used in this study. The latter investigated the relationships between animal frugivores and the fruits that they consume in primary and logged forests. The study was conducted within the Ulu Segama Forest Reserve in primary and logged forests of eight years old, 11 years old and 19 years old. The animals were surveyed using a line-transect method in which a fixed length of a trail marked at every 20 m was walked at a constant speed day and night. Animals sighted were recorded and the distance measured. Five tree-sample plots, each measuring 100 x 20 m, were located along 2-km trails in primary forest and a nine years old logged forest. All trees greater than 10 cm DBH were marked, tagged and identified. Other parameters measured were tree, bole and crown height and crown diameter.

9.2.2.5 Estimating wildlife density in reduced impact logged area

The effect of RIL on wildlife density has not been investigated in the Ulu Segama Forest Reserve. In the absence of primary data to meet the main study objective of comparing the effects of CL and RIL, the ungulate density in RIL units is estimated by extrapolating from known ungulate densities in logged forests of different damage levels following CL.

The model used in this study utilizes the ungulate data reported by Heydon and Abdul Hamid (1994) for primary and logged forests. Their data from logged forests of different ages since logging were treated as equivalent to three different levels of logging disturbance. A 12 year old regenerating forest is considered equivalent to a light disturbance, a five-year old forest to a medium disturbance, and a recently logged two-year old forest to a heavy disturbance. This model rests on the assumption that the effect on animal population of time elapsed since logging can be considered as equivalent to variation in initial logging intensity. Justification for this is provided by the evidence of the slower rate of forest recovery following CL than RIL (chapter 4 and 5) and the fact that this study is concerned with wildlife values over the full rotation of 60 years. The following steps were taken in developing the model:

(a) Plot ungulate densities (*Trangulas javanicus, T. napu* and *Muntiacus* spp.) against undisturbed and the three different levels of logging disturbance (on the basis of the proportion of total number of trees damaged). Trendlines are then fitted through the four sets of actual data using a power equation in Microsoft Excel of the form $y=cx^n$, where c is a constant and n is the power (Figure 9.1)

(b) Extrapolate from (a) the ungulate densities for RIL units from known damage level caused by RIL techniques (18 % of total number of trees in RIL were fatally damaged i.e. with crown snapped-off or killed during logging)

(c) Plot another graph of ungulate densities against time up to 60 years (Figure 9.2). Fit a curve through the four data points (primary and logged-forests at year 2, 5 and 12). The lines were fitted by hand as the lack of data points could not give a good fit using a standard statistical package. Then, extrapolate this curve up to the primary forest values to derive the change in animal density over 60 years assuming that hunting is not preventing this trend from collapsing

(d) With the graph in (c), determine the ungulate densities for RIL at t_0 using extrapolated values obtained in (b) assuming that RIL follows the same curve, and that ungulate density in year 0 and 1 have the same values as year 2.

This model is used to estimate the impact of RIL on the two species of mouse deer and the barking deer species but not for sambar deer and wild pig. The reason for not carrying out such an extrapolation of the sambar deer and pig densities is that

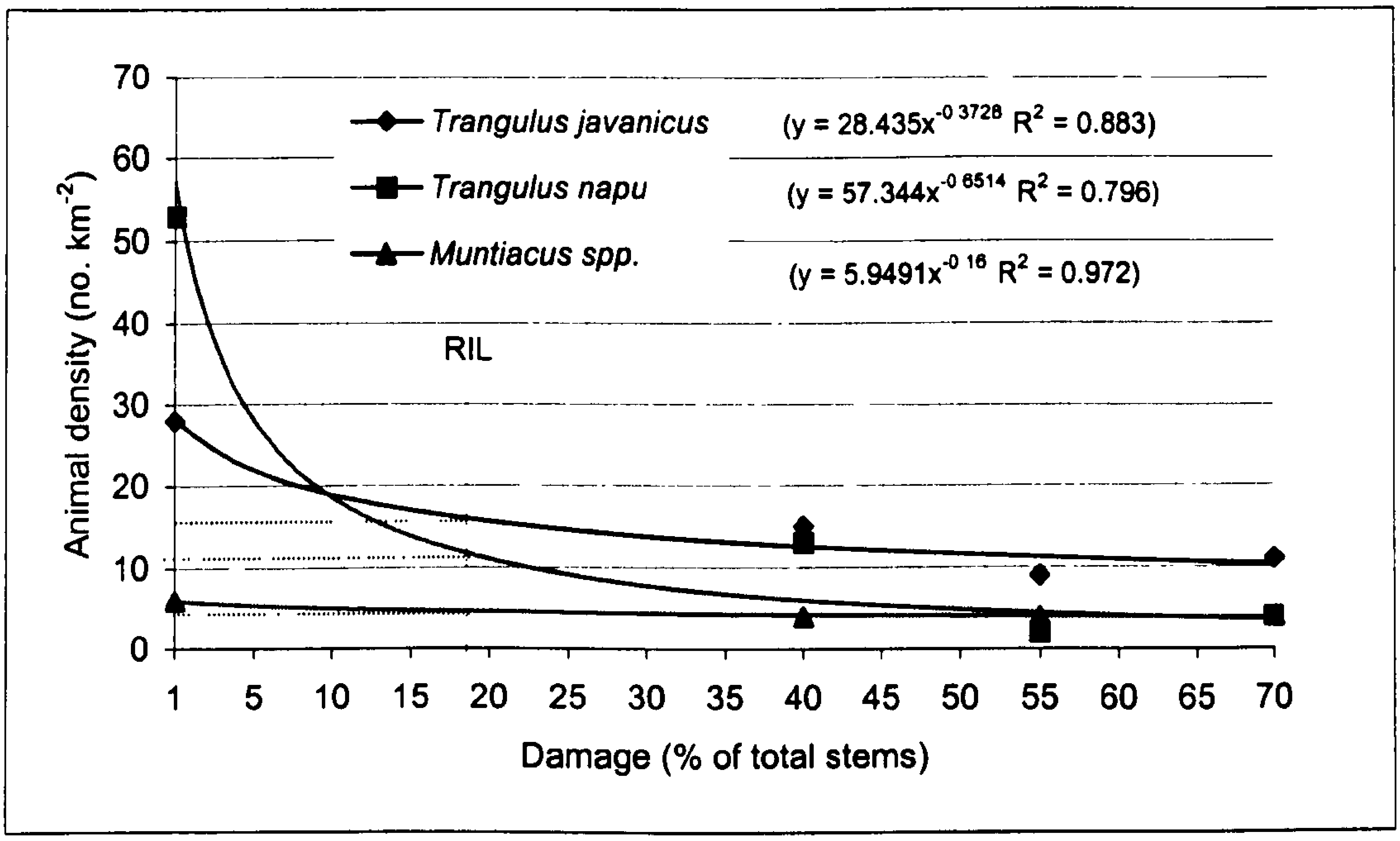


Figure 9.1 Wildlife density of three ungulate species (*Trangulus javanicus, T. napu* and *Muntiacus* spp.) in RIL units extrapolated from wildlife density in primary forest (0 % damage) and at different ages since conventional logging (2 years = 70 % damage (heavy); 5 years = 55 % damage (medium); 12 years = 40 % damage (light))

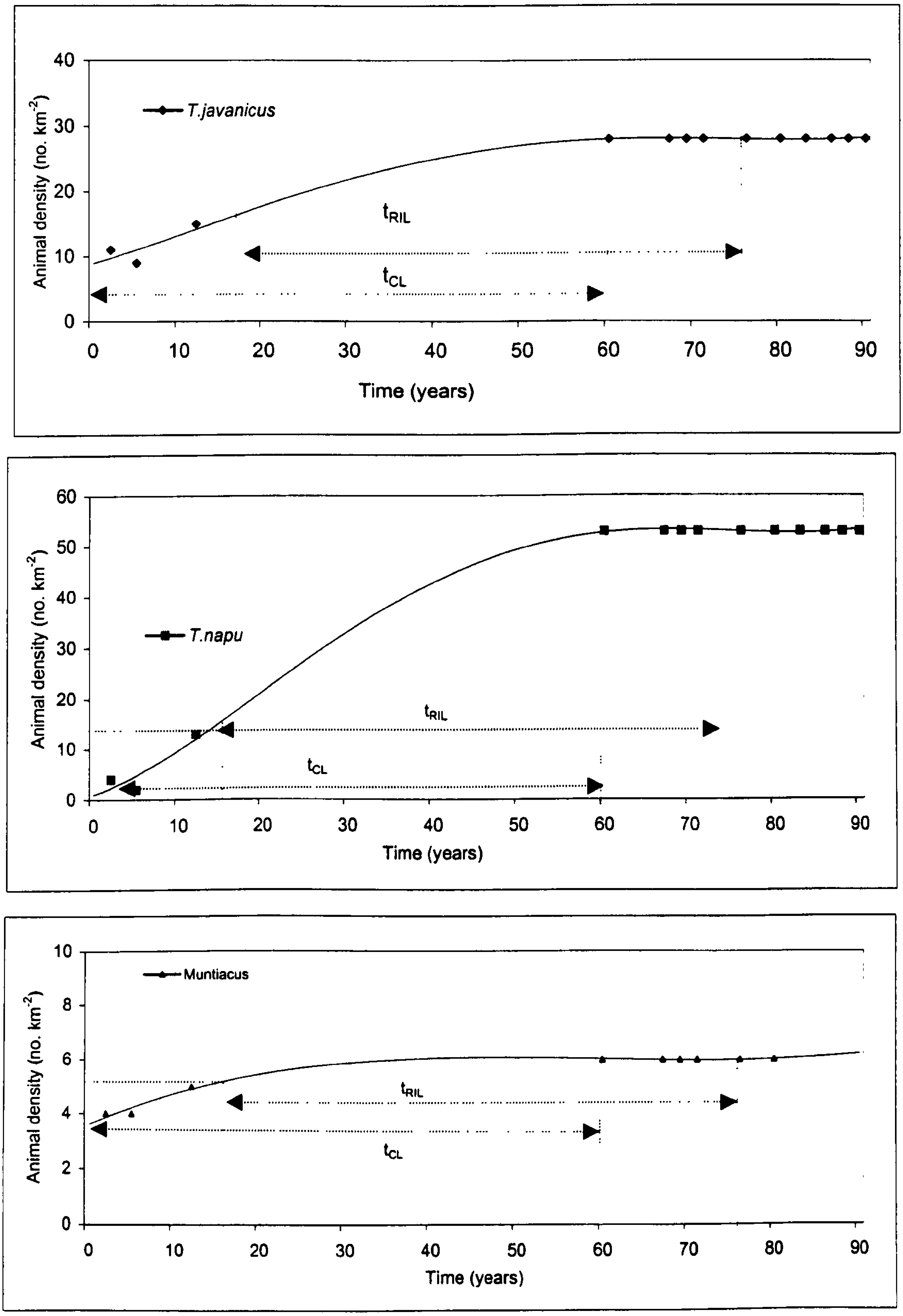


Figure 9.2 Projected wildlife density of three ungulate species based on three different ages of forest since logging

previous studies have found that the densities of these two species are similar in primary and logged forest within the Ulu Segama Forest Reserve (Heydon and Abdul Hamid, 1994; Norhayati *et. al.*, 1998). Sambar deer tolerate both closed and open forest habitats; feeding mainly on shrubs less than two metres above ground which grow in primary and logged forests. Another reason for not applying the model to sambar deer is that sightings in the Ulu Segama Forest Reserve are too few to produce a meaningful graphical relationship of the model. Similarly, pigs are also generalist species that are able to browse in both types of forest and they, therefore, have a similar abundance in primary and logged forests (Davies and Payne, 1982). Wild pigs, however, have a high breeding rate because of their diverse diet, short pregnancy gestation length (three to four months), and a high fecundity with approximately three to ten foetuses per female (Caldecott, 1988).

9.2.3 Valuing wildlife target group

9.2.3.1 Valuation techniques

There are different techniques of valuing wildlife benefits depending on their uses. Wildlife species may be hunted and consumed for their meat without being traded in the market. Economists treat such use as a *consumptive use value* or a non-market value because its value normally does not enter the national income account (McNeely *et. al.*, 1990). Consumptive use value can be assigned a price if the product were sold on the market instead of being consumed. For example, hunted pigs had a market value of some RM100 million per year in Sarawak, Malaysia (Caldecott, 1988). Conversely, animal skins, musk, ivory or carcasses harvested for game meat are valuable wildlife products that may be harvested and exchanged on the market for monetary value. These products are treated as *productive use value*. Often, this is the only value of wildlife that is reflected in national income accounts. In Zimbawe, for example, Cumming (1985) estimated that potential gross return from wildlife utilization for game meat amounted to RM30 ha^{-1} (USD12 ha^{-1}). The basis for calculating the net value of consumptive use is based on market prices minus harvesting costs (Navrud, 1992)

Wildlife can also be treasured for its existence where some people derive satisfaction, e.g. from bird-watching, or study it for scientific research. In such case, wildlife has *non-consumptive use* value that is not traded in the marketplace or reflected in national income accounts. Non-consumptive use is usually evaluated based on the consumer's willingness-to-pay. Under the willingness-to-pay approach, the most frequently employed methods of evaluating wildlife benefits are the travel cost method, and contingent valuation. The travel cost method uses information on the amount of money and time people spend in getting to a recreation site to estimate their willingness to pay for the use and facilities of that site. This method has been used successfully for studies of the recreation and hunting values of wildlife, for example, Brown and Henry (1993) valued elephant viewing in Kenya. The main criticism of the travel cost method, however, is that it cannot estimate non-use values such as existence value. The alternative approach is the contingent valuation method which uses surveys to ask people directly what they would be willing to pay for a specified change in the quantity or quality of wildlife benefits, rather than to infer them from a demand curve (as in the travel cost method). The main attraction of the contingent valuation method is that it can measure non-use values such as existence value. The disadvantage of this method is that its measure is based on responses to hypothetical markets, rather than observed market behaviour (Jakobsson and Dragun, 1996).

The consumptive use value is of relevance to this study because the sambar deer, barking deer and bearded pigs are among the most heavily consumed animals in the Borneon territory. In Sabah, Stuebing *et. al.* (1993) estimated that the economic value of wild venison meat alone was nearly RM30 million per year on the basis of 148,548 animal kills annually, with each animal yielding 40 kg of edible meat at a retail value of RM5 kg^{-1}. In Sarawak, the wild meat trade for bearded pig, sambar deer and barking deer amounted to RM100 million per annum (Caldecott, 1988). The basis of this valuation was the cost of replacing wild meat harvest with the cost of livestock husbandry. If wild meat harvest was valued based on the price of equivalent food, i.e. mixed-grade pork at RM9.00 kg^{-1}, total wild meat value in Sarawak would increase to RM162 million on the basis of 18,000 tonnes of wild meat being harvested per year (Caldecott, 1988).

In order to determine the consumptive use value of the wildlife target group in this study, there is a need to estimate: (a) the harvest levels for the 60 years; (b) the price of the wildlife meat; (c) the harvesting costs, and (d) the net value of wild meat and the net present value of wild meat harvest over 60 years. The methods to achieve these four steps and their bases are given in the following.

9.2.3.2 Determining the harvest levels

Wildlife harvesting programmes based on a sustainable concept have not yet been introduced in Sabah (Stuebing *et. al.*, 1993). One of the key problems for this shortfall is the lack of specific information required by such sustainability models i.e., (a) the extent and variation in patterns of hunting, (b) the population status of game species, (c) the productivity of game populations, and (d) the response of game populations for rural communities or for tropical forest game species (Robinson and Redford,1994). This is a common problem in most countries in the tropics (Robinson and Redford, 1994). Most sustainability harvest models, however, are formulated based on the minimum and maximum age of animal production and fecundity with strong correlation to animal size.

The harvest levels for this study were based on those which have been prescribed by past studies in the tropics. Out of five studies reviewed for different animals and sizes (Healey, *unpubl.*), the sustainable harvest levels for each species mostly fell into two groups: one with a range between 1 % and 21 % (mean = 13 %, n = 12, Table 9.2), and the other with a range between 31 % and 72 % (mean = 44 %, n = 11). These proportions approximated the estimates suggested by Robinson and Redford (1991) who estimated that sustainable harvest rate to be 20 % of annual production for long-lived species with a life span of 10 years or more, and 40 % of annual production for short-lived species with a life span of 5-10 years.

From the above, this study adopts two harvest scenarios with a 10 % and 40 % culling rates, respectively, both rates were lower than those found in the literature review. The reason for using lower estimates was consistent with Clayton *et. al.'s* (1997) study which found that wild pigs have intrinsic rate of increase between 0.35 and 0.62 per annum with a mean value of 0.48. Other studies implied that approximately 20 to 40 % of that rate may be harvestable sustainably (e.g. Robinson and Redford, 1994; Wilson and Johns, 1982; Fa *et. al.*, 1994; Winterhalder and Lu, 1997). These values support the use of a 10 % and 40 % culling rate for the two scenarios although the lower estimate may be more realistic for pigs.

9.2.3.3 Pricing wildlife benefit

The prices for the wildlife target group were based on retail price information (1996) collected from Lahad Datu - the nearest town from the study area. Based on the survey, mousedeer meat was sold at RM4 kg^{-1}, bearded pig at RM5 kg^{-1} and sambar deer at RM6 kg^{-1}.

9.2.3.4 Estimating wildlife harvesting costs

As a matter of policy, hunters must first obtain a hunting licence from the Sabah Forestry Department, and then permission from the forest enterprise to enter the forest concession for hunting (outside conservation and active logging areas).

Within the forest concession where this study was carried out, it requires approximately two and a half hours of driving from the nearest town (Lahad Datu) to the hunting zones. Hence, hunters (usually two or more) come with their own vehicles. The most common method of hunting in Sabah is by driving along access roads, and spotting

Table 9.2 Summary of sustainable harvest levels (percentage) that have been adopted in tropical countries as a basis in determining the culling rates for this study

No. Author	Methods	Animal species	Variables	Percent
1 Bodmer (1994)	Production divided by density	*Toyassu tajacu* (peccary)	1.83 / 3.30 =	55.45 H*
		T. pecari	0.80 / 1.30 =	61.54 H
		Mazama american (red deer)	0.60 / 1.80 =	33.33 H
		M. gouazoubira	0.30 / 0.80 =	37.50 H
		Tapirus terretris (tapir)	0.05 / 0.40 =	12.50 L
2 Feer (1993)	Maximum sustainable yield (MSY=0.5 x rm x K) divided by biomass	*Cephalophus monticola* (Duiker)	54.40 / 257.20 =	21.15 L
	where rm is therate of increase expressed as percentage of the population	*C. leucogaster*	2.80 / 18.70 =	14.97 L
	(rm calculated from Caughley and Krebs (1983) equation: $rm = 1.5 \times W^{0.36}$ where W in Kg	*C. nigrifrons*	3.00 / 20.50 =	14.63 L
	K is the carrying capacity	*C. callipygus*	21.10 / 168.50 =	12.52 L
		C. dorsalis	13.80 / 109.20 =	12.64 L
		C. sylvicultor	3.70 / 45.40 =	8.15 L
3 Fa *et. al.* (1994)	Robison and Redford method	Ungulates	2.02 / 13.00 =	15.54 L
	The model derives a wildlife population's rate of increase according to Cole's (1954) formula:		8.68 / 22.60 =	38.41 H
	$1 = e^{-r} + be^{-r(a)} = be^{-r(w+1)}$ where		0.50 / 3.80 =	13.16 L
	r is the maximum intrinsic rate (as a percent of the total population) of increase of a population not		1.31 / 4.10 =	31.95 H
	limited by food, space, resource competition or predation; r is assumed to be achieved at 0.6 K		0.29 / 0.90 =	32.22 H
	(i) rmax is achieved at 0.6 K		8.57 / 22.60 =	37.92 H
	(ii) rmax can be achieved in game populations		1.89 / 3.10 =	60.97 H
	(iii) that harvested populations can be managed so that they remain at or near 0.6 K			
	a is the age at first reproduction;			
	b is the annual birth rate of female offspring			
	w is the age at last reproduction; and			
4 Fitzgibbon et. al. (1995)	Robison and Redford method	*Cephalophus* spp.	36.20 / 62.70 =	57.74 H
5 Noss (1998)	Logistic model	*C. dorsalis*	=	3-17 % L
		C. callipygus	=	2-13 % L
		C. monticola	=	1-13 % L
		Atherurus africanus (Porcupine)	=	11-72 % H

Note: L=Low culling rate; H=High culling rate: The mean of L is 12.7 (n=12) and for H is 44 (n=11) animals using a powerful spotlight to 'blind' the animals. Occasionally, hunters go on foot to hunt at a speed of approximately 2 km/h for several hours into the night.

The number of successful hunts per outing depends on the hunters' knowledge of the animals' behaviour and habitat, the time of the year, the forest conditions and to a certain extent – 'luck'. With a successful hunt, hunters would carry the kill to their vehicle and drive back to their destination. The dead animal may be for own consumption or sold to their customers.

The costs of harvesting would include the cost of bullets used, labour time directly associated with finding, extracting, processing, and transporting the goods from the forest to the market. In some studies, opportunity cost has been used for the time-spent hunting or travelling (Clayton *et. al.,* 1997) which represent the implicit wage earned by the hunter, and is calculated as the wage available in the next most profitable alternative employment. Hunters' costs vary from place to place depending on the distance traversed, the opportunity costs, price of gasoline, bullets etc. This study assumes that harvesting costs is approximately at 50 % of the price per kg of animal kill based on a preliminary survey carried out in the Sabah Foundation forest concession (Gasis *pers. comm.*).

9.2.3.5 Estimating net value of wildlife

To calculate the value of each animal killed, the carcass weight was estimated and multiplied by the price per kilogram of meat value. Carcass weight of mousedeer ranged between 2.4-4.2 kg per animal. The barking deer with a bigger body size than mousedeer had carcass weight of 13 kg per animal. In the case of sambar deer, a mean carcass weight of 50 kg per animal was used. The pig's carcass weight was estimated to be 30 kg per animal. These carcass weights were obtained from personal interviews with hunters who frequented the Sabah Foundation forest concession.

The annual total value of wildlife meat harvest in forests logged with RIL and CL techniques was estimated by multiplying the value per animal killed with the animal density found in the two treatment areas. The annual animal density was calculated based on the method described in section 9.2.2.5, and the harvestable quantity at 10 % and 40 % are then estimated from the no hunting statistics.

The net present value of the benefits and costs from wildlife harvest are then summed and discounted at discount rates between 2 % and 10 % at 2 % intervals.

9.3 Results

9.3.1 Animal density at t_0

9.3.1.1 Primary versus logged forests

The findings of Heydon and Abdul Hamid (1994) on the ungulate density between primary and conventionally logged areas are summarised in Table 9.1. The densities of mouse deer (*T. javanicus*) for different ages of logged forests (two years, five years and 12 years old) were 11, 9 and 15 animals km^{-2}, respectively and were generally lower than those found in primary forest (28 animals km^{-2}). For another species of mouse deer (*T. napu*), its density varied between the three ages of logged forests with the highest density found in 12 years old forest (13 animals km^{-2}) but this was lower compared with its density in primary forest (53 animals km^{-2}). The estimated density of barking deer in logged forests averaged 4 animals km^{-2}; two-thirds of the density in primary forest. The densities of sambar deer in the two and five years old forests averaged 2 animals km^{-2} and were higher than in primary forest (1 animal km^{-2}).

For wild pigs, Norhayati *et. al.* (1998) recorded 70 animals km^{-2} in primary and logged forests in the Ulu Segama Forest Reserve. The density of bearded pig reported by Norharyati was higher than estimates amongst other studies elsewhere. For example, Wilson and Johns (1982) have data for bearded pigs at approximately 13.4 pigs km^{-2} in primary forest and 1.4 pigs km^{-2} in three to five years old logged forest. They found a greater reduction following logging. Most other studies like Clayton *et. al.,* (1997) reported much lower pig density of 1.25 pigs km^{-2} (500 pigs in 400 km^{2}) and 12 pigs km^{-2} despite high intrinsic rate of increase between 0.35 and 0.62 per annum for two pig species. The difference in pig density among studies depends largely on hunting pressure, which is the exception in the study area in Sabah. However, the bearded pig has a large average litter size (three to 12, depending on mother size); short gestation length (90-120 days) with up to two litters per year; variable but potentially early age at first rut and pregnancy (10-20 months); consumed at least 50 genera of plants; efficient conversion of dietary fat to body fat; variable but potentially high growth rates; very flexible group sizes (tens to hundreds); and travel-adapted features, such as long legs and swimming ability (Caldecott, 1988).

Nevertheless, Norhayati's estimate of bearded pig density is comparatively on the high side. Furthermore, the margin of error (double counting) in inventorying wild pigs in the forest is also relatively high because they are highly mobile animals and have a wide range of diets, and can exist in logged and primary forest (Norhayati, *pers. comm.*). This study, therefore, adopts only 50 % or 35 pigs km^{-2} of the 70 pigs km^{-2} reported in Norhayati's study which is still a considerably high estimate against other studies.

9.3.1.2 Primary versus reduced impact logging forests

The extrapolated densities for the two species of mouse deer in RIL forest (16 and 12 animals km^{-2}; Figure 9.2) were lower than in the primary forest (28 and 53 animals km^{-2}, respectively, Table 9.1). The density of barking deer in the RIL units of 5 animals km^{-2} was approximately the same as in primary forest. The densities of sambar deer (1 animal km^{-2}) and bearded pig (35 animals km^{-2}) in the RIL forest were similar to primary forests.

9.3.1.3 Conventional versus reduced impact logging forests

The extrapolated ungulate density in the RIL units had a higher mousedeer density (16 animals km^{-2} for *T. javanicus* and 12 animals km^{-2} for *T. napu*) compared with two years old CL forest of 11 and 4 animals km^{-2}, respectively. The density of barking deer in the RIL units of 5 animals km^{-2} was approximately the same as in two years old CL forest. The density of sambar deer in the RIL forest (1 animal km^{-2}) was lower than logged forests of different ages (approximately 2 animals km^{-2}). The density of bearded pigs, on the other hand, was similar in both RIL and CL units at 35 animals km^{-2}.

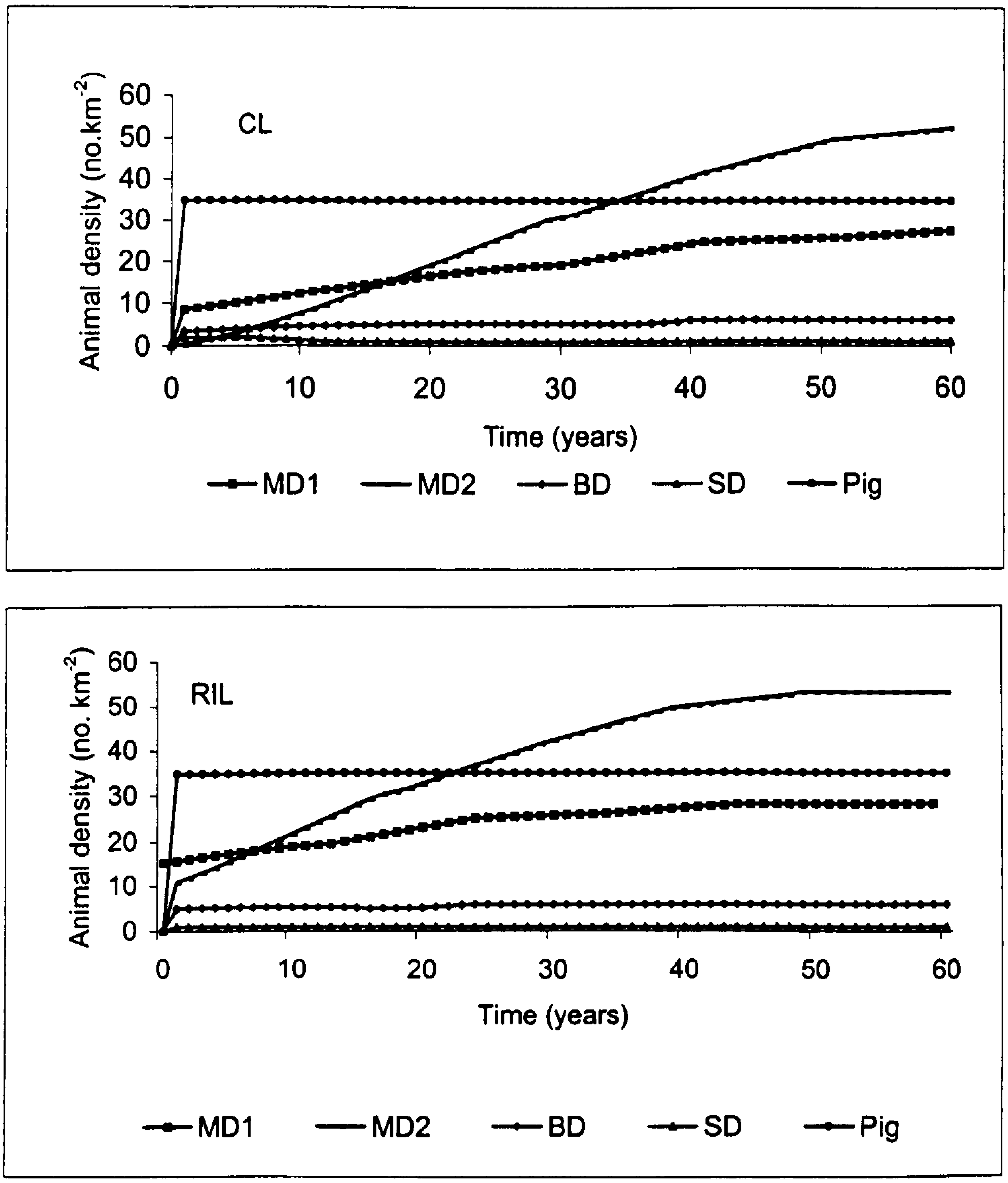
9.3.2 Projected animal density in RIL and CL units ($t_{0\text{-}60}$)

9.3.2.1 No hunting scenario

The mousedeer and barking deer were the only animal groups that showed a significant difference in densities between the RIL and CL units over the 60 years (Figure 9.3). The sambar deer and the pig densities were similar in the two logging units.

In the case of the mousedeer and barking deer, their densities differed in the initial year as well as in the rate of increase between year 0 and 40. At year zero (t_0), the difference in the densities of mousedeer and barking deer between the two logging units was 6, 10 and 2 animals km^{-2}. This gap persisted for the next 30-40 years before converging. By year 60, the animal densities in the two units were about similar.

The mean density of the two species of mousedeer in the RIL and CL forests by year 60 were projected to be 24 and 20 animals km^{-2}, respectively. The mean density of barking deer in the two forests was 39 and 29 animals km^{-2}, respectively. For



Note: MD1=*Trangulus javanicus* MD2=*Trangulus napu* BD=*Muntiacus* spp.
SD=*Cervus unicolor* Pig=*Sus babatus*

Figure 9.3 Animal density in CL and RIL units under 'no-hunting' scenario sambar deer and bearded pig, the mean density in the RIL and CL were similar (1 and 35 animal km^{-2}).

9.3.2.2 With hunting scenario

With harvest levels set at 10 % and 40 %, the population of the wildlife target group in the RIL and CL units were sustainable throughout the 60 years.

If a 10 % harvest level is used, total harvest yields for the two species of mousedeer over 60 years in the RIL and CL units were 144 and 234 animals km^{-2}, respectively (Figure 9.4; Appendix 9.1). Within the RIL units, a total of 34 barking deer km^{-2} could potentially be harvested. The number of sambar deer and bearded pigs harvested was 6 and 210 animals km^{-2} respectively. In the CL units, the harvest yield from the respective animals were 118, 176, 32, 7 and 210 animals km^{-2}.

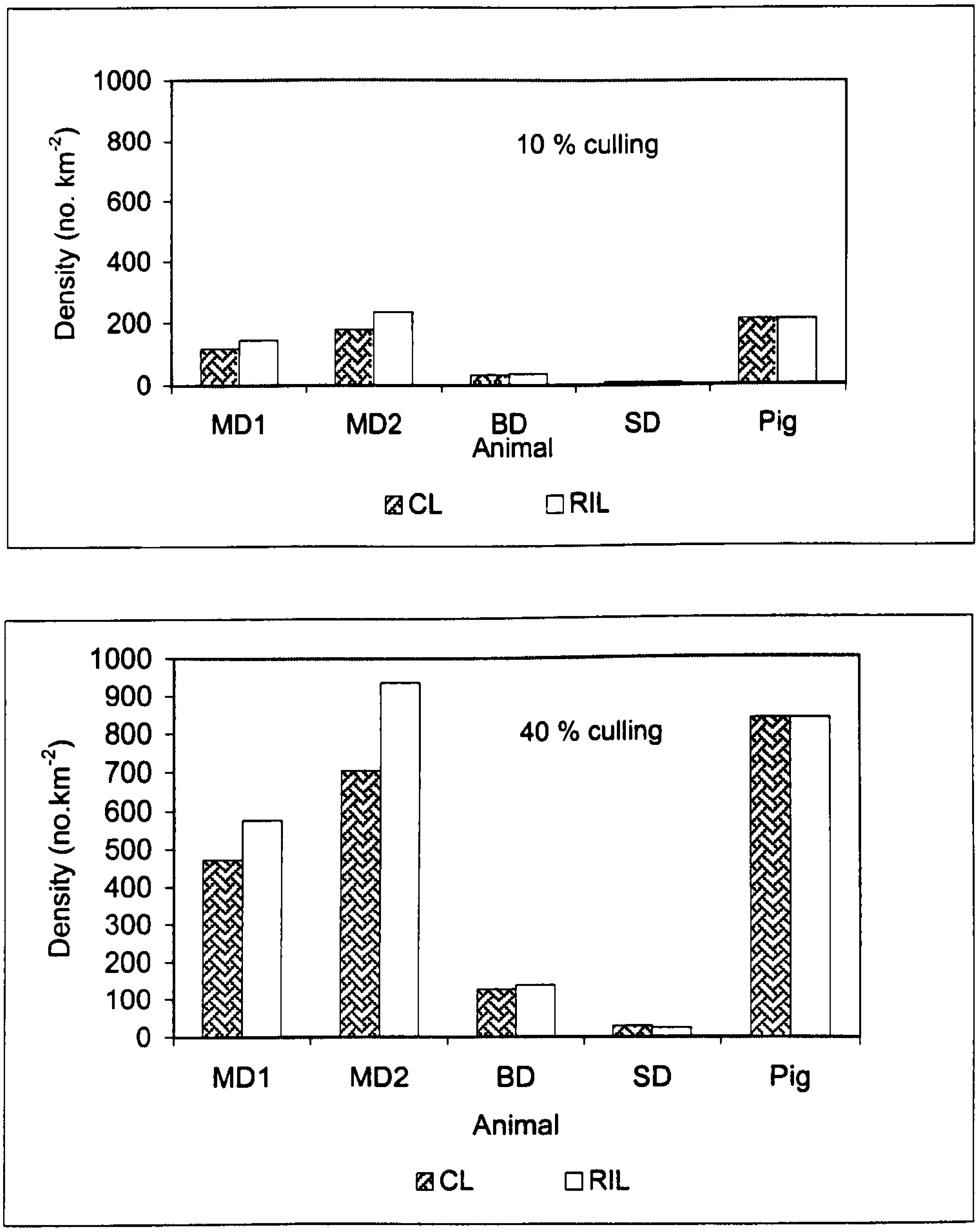
At a 40 % culling rate, harvest yield for the two species of mousedeer were 576 and 936 animals km^{-2}. The harvest yield in the RIL units for barking deer, sambar deer and bearded pig were 137, 24 and 840 animals km^{-2} (Figure 9.4). In the CL units, the yield from the two mousedeer species were 472 and 704 animals km^{-2}, respectively. For barking deer, sambar deer and bearded pigs, the harvestable quantities were 126, 29 and 840 animals km^{-2}, respectively.

By year 60, the population densities for the two species of mousedeer in the RIL units were 25 and 48 animals km^{-2}, respectively at a 10 % culling rate (Figure 9.5; Appendix 9.1)). In the CL, the mousedeer densities were 25 and 47 animals km^{-2}. For barking deer, sambar deer and bearded pigs, the densities in the RIL and CL units were little affected by the culling at 10 %, and the densities in both units were at 5, 1 and 32 animals km^{-2}. At a higher culling rate of 40 %, the densities for the two mousedeer in the RIL units over 60 year were 17 and 32 animal km^{-2}, respectively (Figure 9.6). For the CL units, the two mousedeer densities were 17 and 32 animals km^{-2}. The densities for barking deer, sambar deer and bearded pig in the two logging units were similar at 4, 1 and 21 animals km^{-2}.

9.3.3 Economic value of wildlife

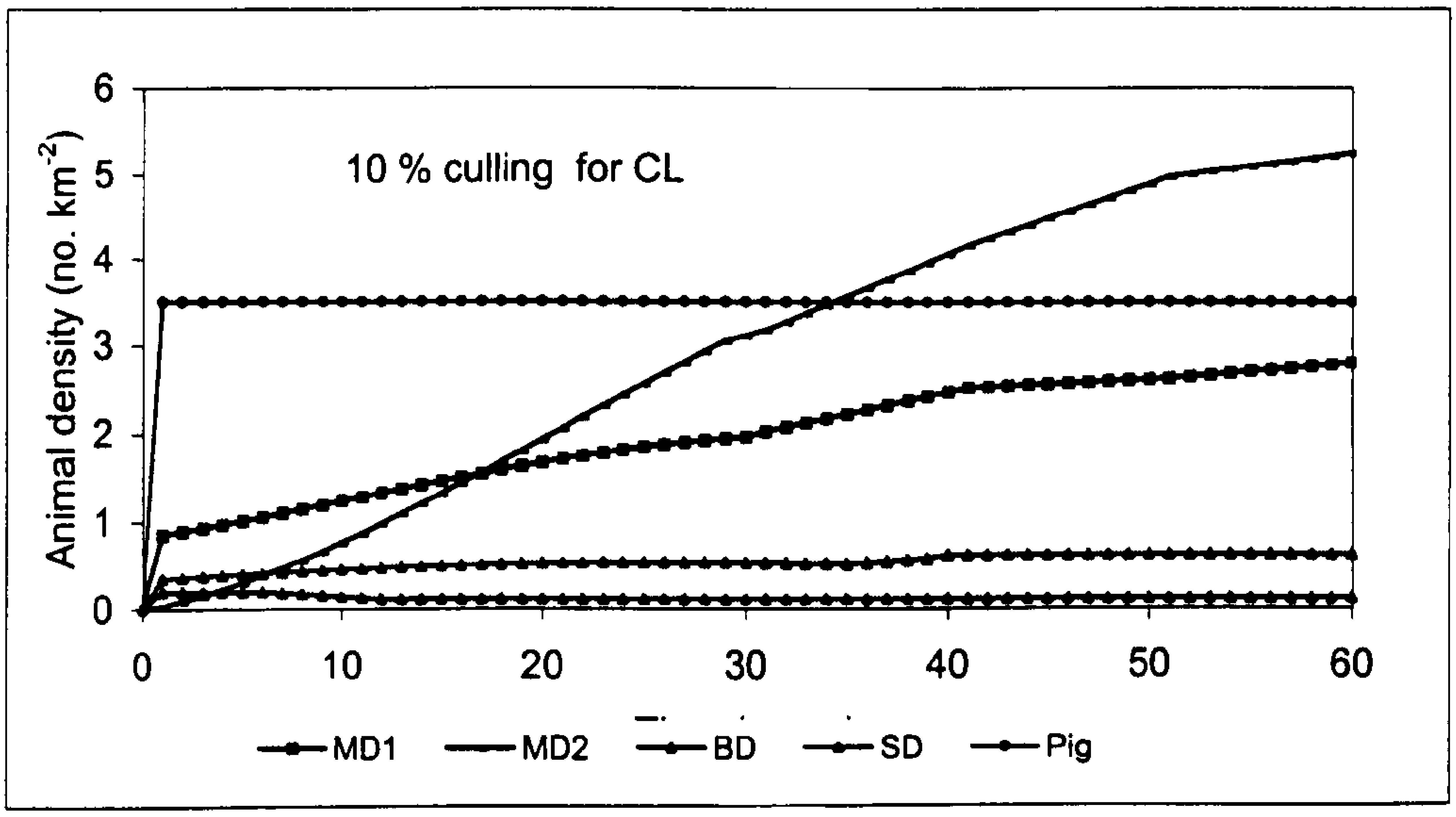
9.3.3.1 Wildlife harvests

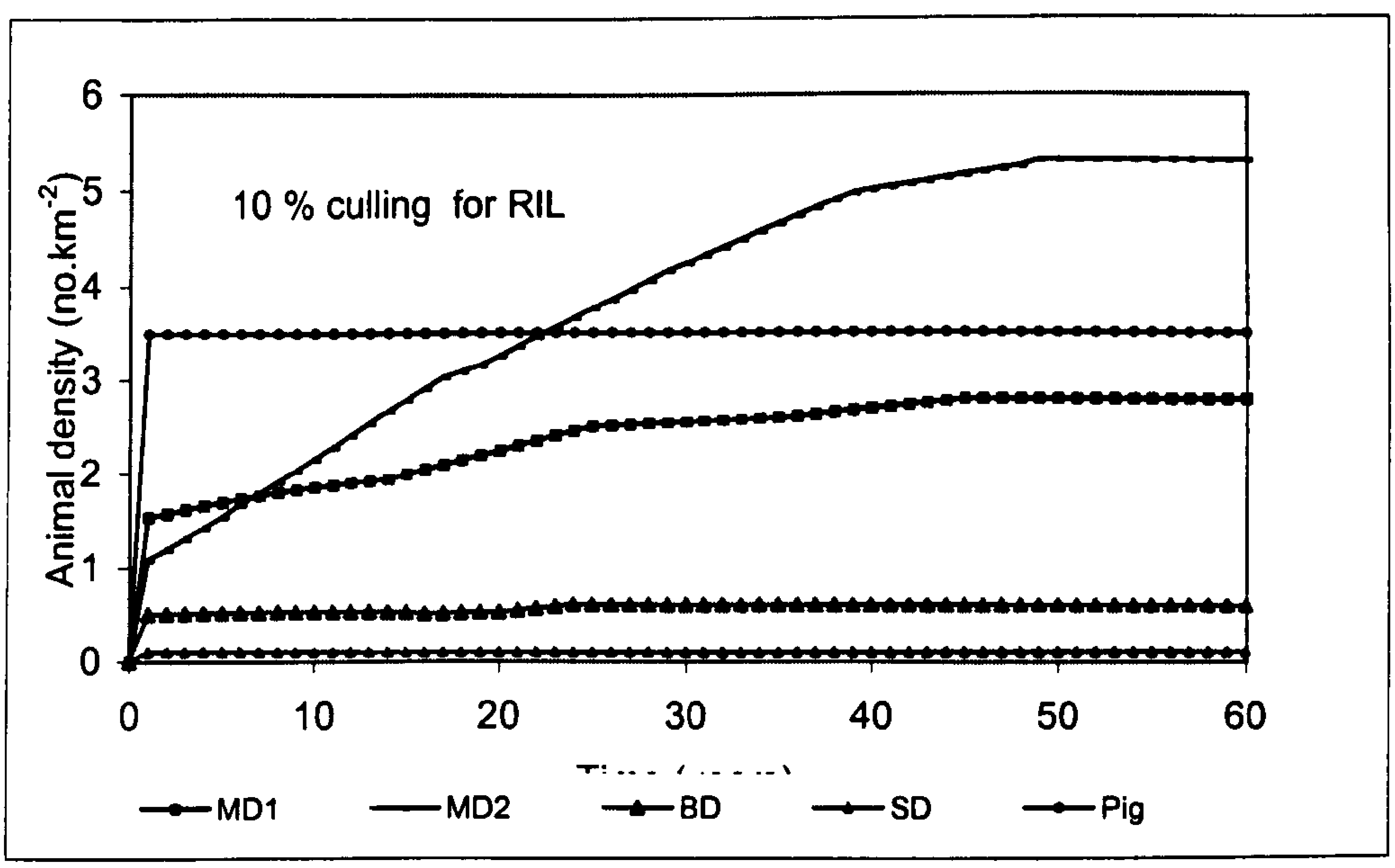
The potential total per square kilometre of animal harvest in RIL units over 60 years was higher than CL units at both 10 % and 40 % culling rates (Table 9.3). RIL units yielded totals per square kilometre of 576 and 936 mousedeer; 137 barking deers; 24 sambar



Note: MD1=*Trangulus javanicus* MD2=*Trangulus napu* BD=*Muntiacus* spp.
SD=*Cervus unicolor* Pig=*Sus babatus*

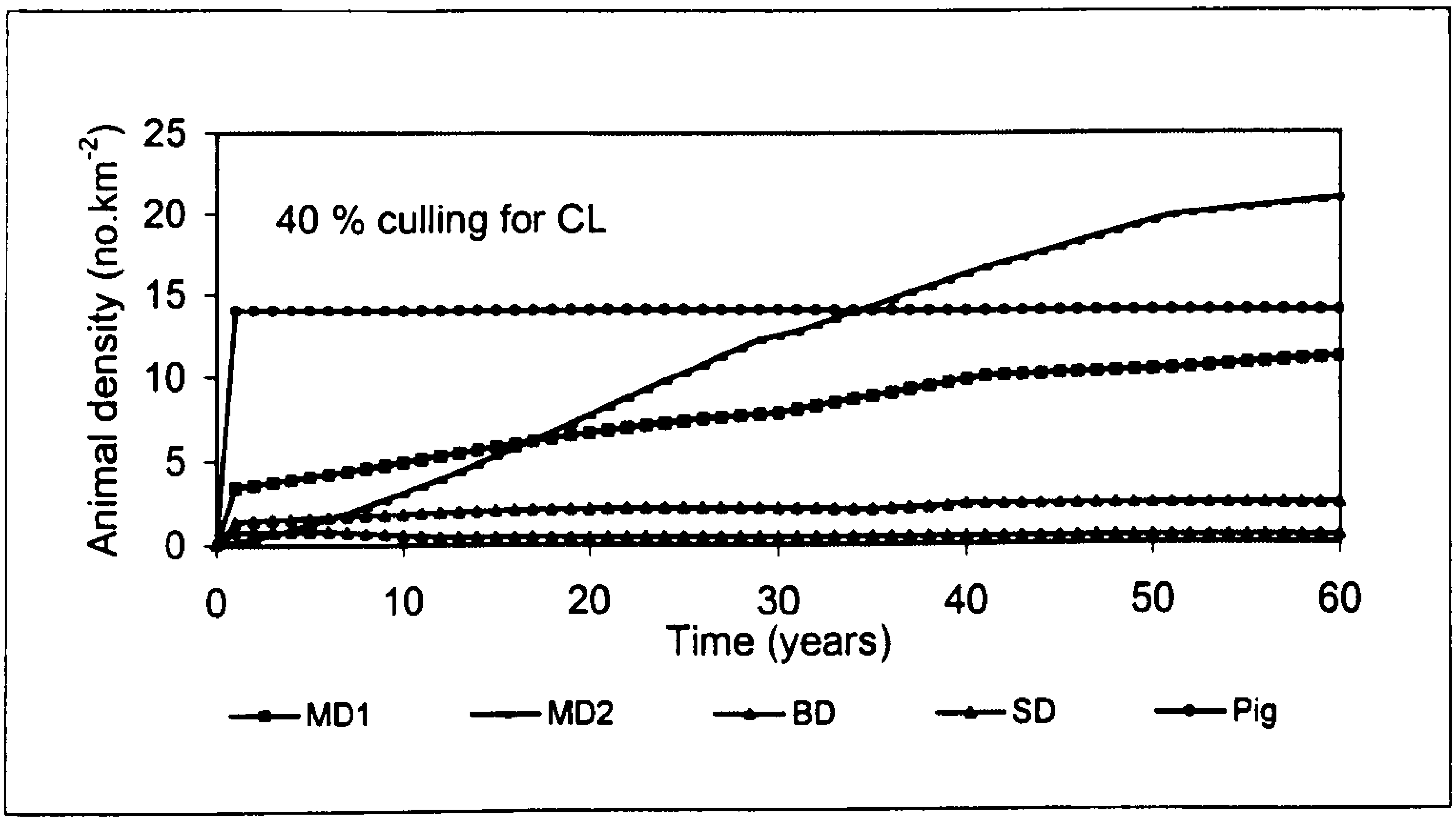
Figure 9.4 Mean total animal harvested in CL and RIL units at 10 % (top) and 40 % (bottom) culling rates

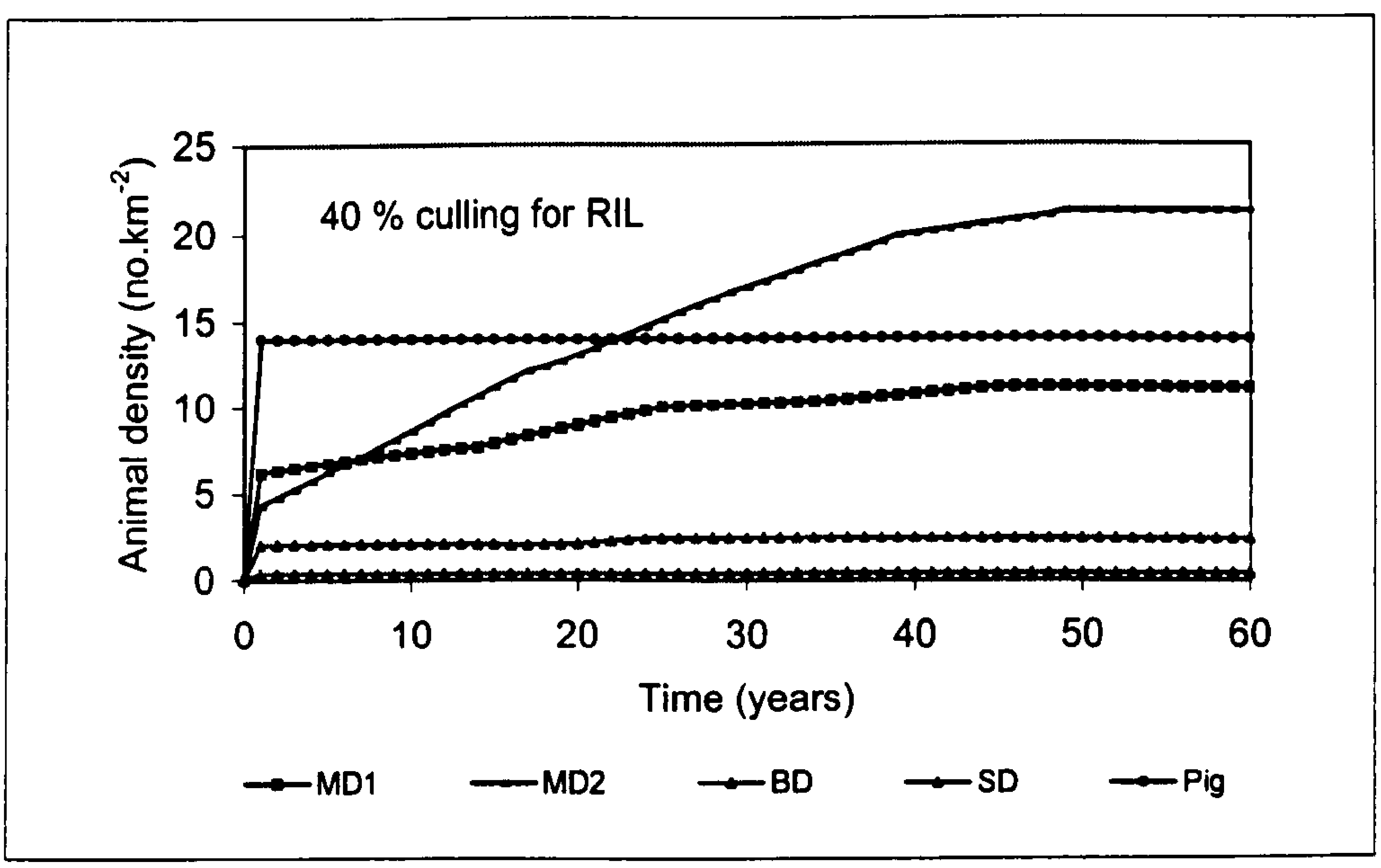




Note: MD1=*Trangulus javanicus* MD2=*Trangulus napu* BD=*Muntiacus* spp.
SD=*Cervus unicolor* Pig=*Sus babatus*

Figure 9.5 Animal density remaining in CL and RIL units after 10 % culling





Note: MD1=*Trangulus javanicus* MD2=*Trangulus napu* BD=*Muntiacus* spp.
SD=*Cervus unicolor* Pig=*Sus babatus*

Figure 9.6 Animal density remaining in CL and RIL units after 40 % culling

Table 9.3 Economic valuation of vertebrate mammals found in the Ulu Segama Forest Reserve over 60 years

	Carcass Weight (kg/individual)	Price (RM kg^{-1})	At 10 % culling						At 40 % culling					
			Primary forest		RIL forest		CL forest		Primary forest		RIL forest		CL forest	
			No km^{-2}	Total RM Km^{-2}	No km^{-2}	Total RM Km^{-2}	No. km^{-2}	Total RM Km^{-2}	No km^{-2}	Total RM Km^{-2}	No km^{-2}	Total RM Km^{-2}	No km^{-2}	Total RM Km^{-2}
1 Mousedeer														
Trangulus javanicus	2 4	4	168	1612 80	144 12	1383 55	118.04	1133 19	672	6451 20	576 47	5534 11	472 16	4532 74
T. napu	4 2	4	318	5342.40	234 09	3932 71	176.00	2956 87	1272	21369.60	936 37	15731 02	704 02	11827 54
2 Barking deer (*Muntiacus* spp)	13 0	4	36	1872 00	34 32	1784 64	31.59	1642 77	144	7488 00	137 27	7138 04	126 37	6571 24
3 Sambar deer (*Cervus unicolor*)	50.0	6	6	1800 00	6	1800 00	7.37	2209 50	24	7200.00	24 00	7200 00	29.46	8838 00
4 Bearded pigs (*Sus babatus*)	30.0	5	210	31500 00	210	31500 00	210 00	31500 00	840	126000 00	840 00	126000 00	840	126000 00
5 Financial analysis														
5.1 No discounting														
Total (RM km^{-2})			738	42127.20	628.53	40400 90	543 0	39442.34	2952	168508.80	2514 11	161603 17	2172 01	157769 51
(RM ha^{-1})				421 27		404 01		394.42		1685 09		1616 03		1577 70
Harvesting cost at	50	%												
Total (RM km^{-2})				21063 60		20200 45		19721 17		84254 40		80801.58		78884 76
(RM ha^{-1})				210.64		202 00		197 21		842 54		808 02		788 85
Net (Revenue - cost)														
Total (RM km^{-2})				21063 60		20200 45		19721.17		84254 40		80801.58		78884 76
(RM ha^{-1})				210.64		202.00		197 21		842 54		808.02		788 85
5 2 With discounting														
Net (RM km^{-2})	2	%		1203.18		11537.88		11242 01		48123.45		46151 53		44968 03
(RM ha^{-1})				12.03		115.38		112.42		481 23		461.52		449 68
Net (RM km^{-2})	4	%		7726.00		7409.41		7216 11		30904.00		29637 65		28864 43
(RM ha^{-1})				77.26		74 09		72 16		309.04		296 38		288 64
Net (RM km^{-2})	6	%		5457 15		5233 53		5100 89		21828 67		20934 12		20403 57
(RM ha^{-1})				54 57		52.34		51 01		218 29		209 34		204 04
Net (RM km^{-2})	8	%		4141.93		3972 21		3877 32		16567 80		15888 84		15509 30
(RM ha^{-1})				41.42		39 72		38 77		165.68		158.89		155.09
Net (RM km^{-2})	10	%		3312 73		3177.03		3106 72		13251 17		12708 13		12426 89
(RM ha^{-1})				33 13		31 77		31 07		132.51		127.08		124.27

Note
1 Body weight of animals from Payne *et al.*, 1985
2 Price based on market survey in Lahad Datu, Sabah
3 Animal density based on Heydon and Abdul Hamid, 1994 and Norhayati, 1997
4. Total value calculated by multiplying body weight per animal by price and number found in primary or different ages of logged forests

deers and 840 bearded pigs. In CL units, the corresponding total harvestable yields were 472, 704, 126, 29 and 840 animals km^{-2}, respectively.

9.3.3.2 Wildlife value

Among the wildlife target group, the bearded pig contributes 80 % of the total revenue in both the RIL and CL units (Table 9.2). The mousedeer, particularly, the *T. napu* ranked second followed by the sambar deer.

With a 10 % culling rate, the estimated net value (after deducting costs) of wild ungulates harvest in forest logged with RIL techniques over 60 years amounted to RM20,200 km^{-2} or RM202 ha^{-1}. This amount was only slightly higher than that in CL units at RM19,721.83 or RM197.22 ha^{-1}. The net difference between RIL and CL units amounted to RM479.21 km^{-2} or RM4.79 ha^{-1}. If a 2 % discount rate was used, the respective total amount would reduce to RM11,537.88 km^{-2} or RM115.38 ha^{-1}, and RM11,242.01 or RM112.42 ha^{-1} for RIL and CL, respectively. At a higher discount rate of 10 %, the net value from the wildlife target group in both the RIL and CL units was reduced by 6.3 times compared with no discounting.

At a 40 % culling rate, the economic value of wildlife harvest in the RIL units increased to RM80,801.50 km^{-2} or RM808.02 ha^{-1}. The CL units yielded RM78,884.68 km^{-2} or RM788.885 ha^{-1} over 60 years. The net difference in value amounted to RM1,920 km^{-2} or RM19 ha^{-1}. When discounted at 2 %, the total harvest value and the value on a per hectare basis in both RIL and CL units reduced by 50 %. The decrease in value was more drastic as higher discount rates were used. With a 10 % discount rate, the reduction was 6.3 times that of without discounting.

9.4 Discussion

This case study found that forest logged with RIL or CL techniques retained economic benefit in terms of wildlife meat harvest. In RIL units, they were valued between RM202.00 ha^{-1} and RM808.02 ha^{-1} and in CL units between RM197.21 ha^{-1} to RM788.85 ha^{-1} over 60 years with culling rates of between 10 % and 40 %, respectively. The net difference in value between logging techniques were RM4.79-RM19.17 ha^{-1} only. With discounting, the economic value of the wildlife target group over 60 years from RIL and CL would reduce further by approximately 43 % at 2 % discount rate to 84 % if discounted at 10 %.

These values were higher than the estimate for wildlife meat harvest in Sabah, although they are comparable with estimates in Sarawak and elsewhere. In a study of the whole of Sabah, Stuebing *et. al.,* (1993) reported wildlife meat value to be RM1.72 ha^{-1} (calculated from a total harvest of deer meat at RM30 million over the land area of Sabah at 17.5 million ha).

Caldecott (1990) recorded a higher estimate of wildlife meat value for ungulates (sambar deer, mouse deer and pig) hunted in Sarawak at RM125 ha^{-1} based on a total harvest value of RM100 million from a resource area covering 800,000 ha.

Elsewhere, Ruitenbeek (1990) estimated that the value of wildlife hunting in Cross River National Park in Oban, Africa was RM41 ha^{-1} (exchange rate 1USD = RM2.50). In Ecuador of the Amazon, wildlife value was estimated to be RM300 ha^{-1} (Pancar and Gardner, 1981).

Using Wilson and Johns's (1992) data of more negative logging impacts on animal density in Indonesia, the economic value for the wildlife target group would be RM25.70 ha^{-1} and RM2.69 ha^{-1} for primary and logged forest (three to five years old), respectively. By simple extrapolation of taking the median value of these values, the economic value of RIL would be RM14.04 ha^{-1}. This gives a ratio of RIL:CL of 1:0.19 against the RIL:CL ratio of 1:0.95. The former gives a far more significant RIL-CL difference compared with this study.

One of the key assumptions adopted in this case study that has a significant effect on the RIL-CL difference is the animal density data, particularly, beyond 12 years after logging. Within this limitation, the estimates of animal densities adopted in this study for primary and logged forest were within the range of animal densities reported elsewhere. For example, the density of mouse deer (*T. javanicus*) within the Ulu Segama Forest Reserve in primary forest (28-53 animals km^{-2}) was much higher than the 6 animals km^{-2} reported in Indonesia (Wilson and Johns, 1992). The density of mousedeer in this study is, however, conservative adopting the median value reported by Heydon and Abdul Hamid (1994).

The density of barking deer (*Muntiacus* spp.) in the forests of the Ulu Segama Forest Reserve (6 animals km^{-2}) was within the range of 1-7 animals km^{-2} reported in India (Karath and Sunquist, 1992); lower than the 11.6 animals km^{-2} in Indonesia (Wilson and Johns, 1992) but higher than the estimate of 3.1 animals km^{-2} in Thailand (Srikosamatara, 1993).

The estimated density of sambar deer (*Cervus unicolor*) in the Ulu Segama Forest Reserve compares well with densities of 1-4 animals km^{-2} in Thailand (Srikosamatara, 1993), 1-7 animals km^{-2} in India (Karanth and Sunquist, 1992) and 4.1 km^{-2} in Indonesia (Wilson and Johns, 1992). In forests that are relatively more open and include areas of grassland, for example, Khao-Yai National Park in Thailand, densities of sambar deer can exceed 13 animals km^{-2} (Ngampongsai, 1978).

For the bearded pigs, the density reported in this study (35 animals km^{-2}) was higher than the range of 1.25-12 animals km^{-2} reported in two separate studies in Indonesia (Wilson and Johns, 1992; Clayton *et. al.,* 1997). Wilson and Johns (1992) found a greater reduction in the density of wild pigs (1.4 animals km^{-2}) following logging in the Borneon territory of Kalimantan. However, the pig density in Ulu Segama Forest Reserve is relatively low compared with the situation in Sarawak, Malaysia where Caldecott (1988) reported that the median number of bearded pigs killed per 10 families per year in unlogged forests was 100 animals, and in logged forests of one to ten years old , the number of bearded pigs hunted was 32 per family per year declining in numbers as the forest matures.

The studies by Wilson and Johns (1992) and Caldecott (1988) were of particular prominence here because they were conducted within the Borneon territory. Wilson and Johns (1992) found a much lower densities for most animals in primary forest with the exception of the sambar deer. They also reported a much higher decline of animals following three to five years since logging. This trend was also apparent in Caldecott's (1996) study in Sarawak while the present study had assumed the opposite trend: higher density as logged forest recovered from logging. Unlike most of the other study sites, however, the unique feature of the Ulu Segama Forest Reserve study areas was that hunting pressure is relatively low because access by the general public was controlled via security check points and issuance of entry passes. This is an important distinction from other study sites because logged areas were often exposed to an influx of new hunters, and animals are vulnerable to extreme hunting pressure along logging roads (Caldecott, 1996). This explains the difference in animal density between studies referred in this study.

There are two main reasons for the small difference in the economic value of wildlife between RIL and CL units. Firstly, the total value obtained for the higher mouse deer and barking deer populations in RIL units was offset by the decline in sambar deer value compared with CL units. The higher mouse deer population in the RIL units (as many as 5 animals km^{-2} more for *T.javanicus* and 8 animals km^{-2} more for *T. napu* compared with CL units) could be justified by their dependence on fruit trees which were less affected by RIL logging disturbance compared with CL. On the other hand, barking deer were known to be relatively unaffected by fruit abundance while the sambar deer preferred to feed on browse and herbaceous vegetation found in more opened forest canopy (Heydon and Abdul Hamid, 1994).

Secondly, the estimation of ungulate densities in the RIL units was extrapolated from damage levels at different times following conventional logging. This approach may introduce bias because different logging techniques have different impacts on the landscape. For example, the extent of ground openings for roads, skid trails and log landings in the CL units may take an infinitely long time to return to a closed canopy and, if ever, approach the conditions of the RIL units. The significance of ground openings lies in the re-establishment of tree species that may or may not benefit wildlife. Several studies have reported that these openings are commonly occupied by pioneer tree species such as the *Macaranga* spp. which had tiny wind-dispersed seeds (e.g. Pinard *et. al.,* 1996). Heydon and Abdul Hamid (1994) found that ungulates could not benefit from these tiny seeds. Hence, a direct comparison of the impact of different harvesting techniques on wildlife benefit on a *before* and *after* scenario is recommended.

Although this case study found no important difference in the economic value of wildlife between RIL and CL units, reducing the level of incidental damage to forests during harvesting is the most obvious step that can be taken to lessen the impact of logging on wildlife population. Selective logging may represent a disruption of resource availability to a level beyond the extreme of natural disturbances (Johns, 1997). However, it is unlikely that primary forest can continue to occupy large areas, whereas logged forests will continue to expand in size. Large area of logged forest may be the ultimate areas to support species and of potential value in the long term conservation of rain forest animals. By minimising the size and forest gaps caused by logging, this will greatly reduce the chance of animal extinction. Ecologically, reducing open spaces in the logging areas will reduce the invasion of pioneer trees (e.g. *Macaranga* spp.) which are not used as a food resources by the majority of mammalian and avian frugivores (Chivers, 1980). Heydon and Abdul Hamid (1994) found that pioneer species dominated, with 29 % of trees greater than 10 cm DBH in the logged forest in their study area, compared with only 7 % in primary forest. This implies that any change to logging methods which reduces the area of heavily disturbed forest such as on roads, skid trails and log landings and limiting the growth of pioneers should, theoretically, benefit wildlife.

The impact of logging on wildlife will be strongly influenced not just by its intensity/damage level but also by its spatial extent within the landscape (with respect to animal movement patterns). This matter is not specifically linked to the difference in RIL-CL guidelines. If one were to consider that to extract the same total volume of timber one was comparing one scenario where a large proportion of the total forest area was logged at a lower intensity by RIL, compared with a scenario where a smaller proportion of the area was logged at a higher intensity by CL, then:

(i) CL would tend to create a coarser landscape pattern with larger blocks of forest being left intact and unlogged - this would favour wildlife species that are rare and dependent on undisturbed forest habitat;

(ii) RIL would tend to create a finer mosaic of patches of logged and unlogged forest - this might tend to increase the abundance of a larger number of wildlife species that are mobile and able to benefit from the availability of a greater variety of habitat/food source types. Therefore, RIL might tend to be advantageous for consumptive use values, whereas CL may be better for some non-consumptive use values linked to the conservation of rare species. This suggests that a different approach of valuation is necessary.

In fact, one could use the data for primates and birds in Table 9.1 to support the generality of the values that were obtained in this study. For example, if one considers the two groups of animals of greatest value for ecotourism and research (primates and birds), their (lack of) response to logging (different species affected in different ways) does mirror that of the ungulates. Thus one might predict that similar results for the RIL-CL difference (or lack of it) would be produced if different valuation methods were used.

9.5 Conclusion

It is envisaged that using RIL techniques to harvest timbers could potentially retain a higher population of wildlife compared with using CL techniques because RIL creates less logging disturbance on wildlife habitat and their food source. Although the densities of mousedeer, barking deer, sambar deer and the bearded pigs were projected to be higher in RIL units than CL units over 60 years, differences in their economic values were not significant. The results of this study showed that the consumptive use value of this group of animals had an economic value ranging from RM202-808 ha^{-1} and RM192-789 ha^{-1} for RIL and CL, respectively. The main reason for the little difference in economic value of wildlife between the RIL and CL logged units was because wild pig value dominated the overall economic analysis for which their density were assumed to be similar. It may be necessary to include a wider range of animals in future studies if consumptive use valuation is used. They may also be a need to use a combination of valuation techniques such as contingent valuation method to capture benefits for other wildlife populations e.g. birds.

Chapter 10: Cost–benefit analysis

10.1 Introduction

This chapter brings together the findings of the previous six chapters with an attempt to establish the economic worth of a hectare of forest in Sabah after logging, taking into consideration both timber and non-timber forest values. The latter include carbon, soil, rattan, water and wildlife values. The main aim of this chapter, however, is to show what RIL costs per hectare or per cubic metre of wood produce. This aim relates to the world-wide interest and controversy about the cost of reduced-impact logging. RIL is also gaining popularity as a means to retain forest biomass during selective logging as a rapid compensation for CO_2 emission.

The RIL technique that has been described in this thesis actually owes its existence to the carbon interest and has been financed by a utility company based on costs invested in additional logging activities in order to shift from conventional logging practice to reduced impact logging. It has been established in previous chapters that the RIL investment cost approach, however, leaves out many important aspects: i.e. incremental costs (additional costs due to difference in harvest technique), opportunity costs of forgone timber harvest due to RIL restrictions, and last and not least, the non-market benefits and costs. Hence, this chapter will aim to derive a break-even carbon price for RIL which fully compensates for all these aspects. The objectives of this chapter are as follows:

1. To advise a forest planner in Sabah about the *physical value* of different products and services that can be obtained from an area of tropical forest in Sabah subject to conventional logging (this is not a comparison of revenues from logging versus non-timber revenues from a non-logged forest). This objective is distinct from the others as it relates to the world-wide interest and controversy about the relative value of timber and non-timber values from tropical forests.

2. To advise a forest planner in Sabah about the *relative performance* of RIL and CL under current market conditions with respect to the full range of forest values (an analysis of the narrower economic performance with respect to timber values was carried out in chapter 4). There is particular interest in the way that the economic analysis is influenced by the relative extent to which each forest product and service is altered by RIL and CL; the economic value of each forest product (from objective 1); and the effect of discount rate.

3. To perform a cost–benefit analysis of RIL and CL incorporating market and non-market values (a) per representative hectare, (b) per logged hectare, and (c) per cubic metre. The reason for presenting the CBA on each level is:

   (a) if there is a physical limit within the time frame on total land available,
   (b) when there is a political limit on the total area that may be logged, and
   (c) if an overall target timber supply is wanted, with everything else priced.

4. As an addition to the main CBA in objective 3, to make an estimate of the costs of forgone timber harvest associated with RIL on the basis that RIL requires to log a larger area of forest spilling over to another place (hereinafter called the displaced logging scenario) in order to achieve the same volume as CL.

5. To produce a break-even carbon price for RIL incorporating incremental costs, opportunity costs and non-market benefits and costs.

10.2 Methods

10.2.1 The relative physical value of different forest products

This involves summarising the impact of RIL and CL on the timber and non-timber forest values based on the findings of the previous six chapters. These forest values were calculated per logged units (RIL = 129 ha; CL= 175 ha; Figure 10.1).

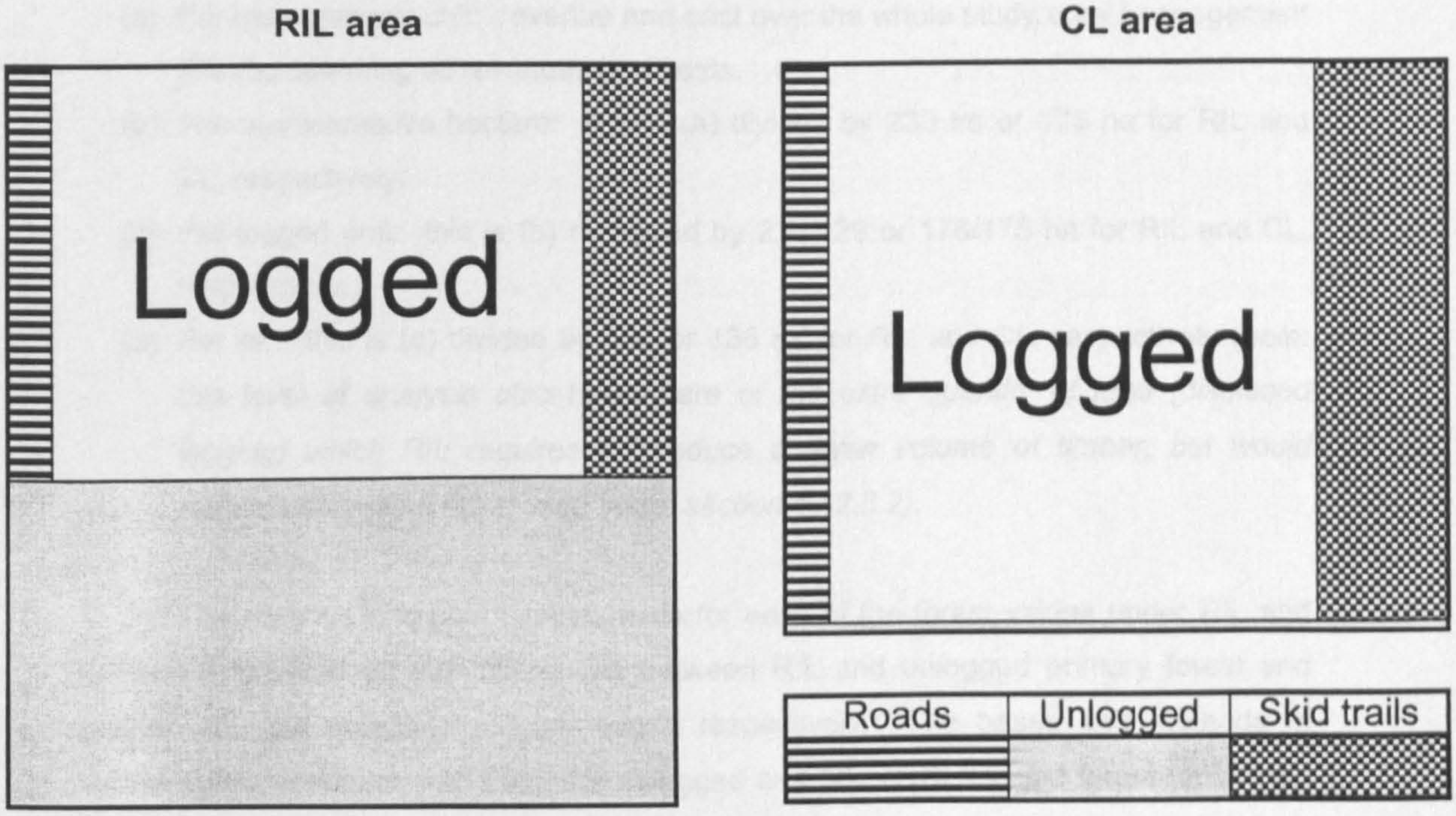
10.2.2 The relative performance of RIL and CL over different forest values

This requires a similar summary as in 10.2.1 showing the absolute influence of CL and RIL on each of the forest products and services (Table 10.1). The main sources of this summary information are chapters 4 to 9. The relative performance of each forest value was calculated by taking the difference between CL and RIL values expressed as a percentage of CL.

10.2.3 Cost–benefit analysis

10.2.3.1 Per hectare and per cubic metre values

The economic assessment of RIL and CL covered two harvest cycles at t_0 (year 0 to 60) and t_{60} (year 60-120) for all forest value except for carbon value which was excluded from the assessment because the main objective was to determine a break-even carbon price for RIL. The reason to consider two harvest cycles in the CBA was to give equal treatment to non-timber values since the CBA for timber value covered two harvest cycles



	RIL (ha)
(a) Logged area	129.0
(b) Unlogged area	101.0
(c) Roads	4.3
(d) Skid trails	0.7
Management unit Total (a + b) =	230.0

	CL (ha)
(a) Logged area	175.0
(b) Unlogged area	1.0
(c) Roads	6.5
(d) Skid trails	21.0
Management unit Total (a + b) =	176.0

Figure 10.1 Schematic representation of the area logged, area unlogged and those occupied by roads, and skid trails in the RIL and CL units. Note that roads and skid trails are part of logged area.

at t_0 and t_{60}. The CBA of non-discounted and discounted values is given in Table 10.2 and Table 10.3, respectively. Table 10.2 shows RIL and CL revenue and cost figures under four column headings, and are calculated on the following bases:

(a) Per management unit: revenue and cost over the whole study area (management unit) by summing all revenues and costs.

(b) Per representative hectare: this is (a) divided by 230 ha or 176 ha for RIL and CL, respectively.

(c) Per logged unit: this is (b) multiplied by 230/129 or 176/175 ha for RIL and CL, respectively.

(d) Per m^3: this is (c) divided by 106 or 136 m^3 for RIL and CL, respectively (*note: this level of analysis also takes care of the extra quantity of land (displaced logging) which RIL requires to produce a given volume of timber, but would remain unlogged if CL is used – see section 10.2.3.2).*

The revenue and cost assessments for each of the forest values under RIL and CL were expressed as the differences between RIL and unlogged primary forest and between CL and unlogged primary forest, respectively. The bases and methods of calculating the revenues and costs for unlogged and RIL or CL logged forest for timber, carbon, soil, rattan, water and rattan values are as follows:

(a) Timber value: the timber revenue and cost figures for RIL and CL at t_0 and t_{60} have been calculated in chapter 4, and used in this chapter without further changes, except that timber royalties, which are a cost to the logging company, but only a transfer for society, are added back in.

(b) Carbon value: the distinctive objective of the CBA is to find a carbon break-even price (denoted as *P*). For non-discounting calculations, carbon value in tonne-years is *P* multiplied by the mean carbon storage multiplied by the time period of analysis (i.e. 120 years). In discounting calculations, *P* is multiplied by the total of discounted carbon flows in tonnes. The t_{0}-$_{60}$ mean carbon storage and flows have been calculated in chapter 5.

(c) Soil values: the aim is to evaluate the timber that is lost on roads, log landings and skid trails (or bare areas). Primary forests are not exploited so it is irrelevant to include in the CBA. For areas logged by RIL and CL, the calculations have been described in chapter 6, and are applied directly to this chapter.

(d) Rattan values: the primary forest would produce a different rattan value from RIL logged forest because it contains a higher rattan stock than a logged forest.

Since there were no actual data collected from the primary forest *per se*, the rattan density was derived from the inventory data collected in the RIL and CL units which covered both logged and unlogged areas (chapter 7). From the inventory data, the rattan density for large and small diameter canes were: 18 and 24 plants ha^{-1} for RIL, and 6 and 18 plants ha^{-1} for CL, respectively. In order to estimate the rattan density of unlogged areas in the RIL units (for the primary forest value), the CL data of 6 and 18 plants ha^{-1}, respectively were used to calculate the expected density in the logged part of the RIL unit. From these, the density in the 0.56 ha logged area in RIL was estimated to be 3.36 and 10.08 plants, respectively. Therefore, subtracting, the density in the 0.44 ha unlogged RIL area would be 14.64 and 13.92 plants. The density for large and small rattan plants per unlogged area from 18 and 24 plants ha^{-1} would, therefore, be 33.27 and 31.64 plants ha^{-1}, and these were assumed to be the densities in primary forest.

The values of the large and small diameter rattan in the primary forest were then re-calculated as per the economic analysis described in chapter 7 using the price and cost assumptions given in that chapter.

For the RIL and CL units, the economic value of the large and small rattan stocks assumed similar values as has been calculated in chapter 7 based on the price and cost assumptions used in that chapter.

(e) Water values: this deals with the eroded sediment from roads, skid trails and log landings which are valued against the opportunity cost of hydroelectricity plus dredging cost when the hydro power plant is shut-down for dredging works. Since there are no bare soil areas in the primary forest, therefore, it has no sedimentation.

The calculations for the cost of sedimentation due to RIL and CL per area logged were the main focus in chapter 8.

(f) Wildlife value: The wildlife values in primary forest and RIL/CL logged forest have been estimated in chapter 9. The methods of calculation can be referred to in the relevant sections in chapter 9, and the data are applied directly here.

10.2.3.2 CBA for displaced logging

There are two scenarios for the displaced logging case (Scenario 1 and 2). Scenario 1 assumes that the extra quantity of land which RIL requires to produce a given volume of timber would remain unlogged if CL is used. The analysis at the per cubic metre level in scenario 1 (section 10.2.3.1) takes care of the displaced logging effects of scenario 1. It looks, in monetary terms, at all the quantitative and monetary consequences associated with logging a cubic metre by RIL or by CL.

Scenario 2 of the displaced logging case assumes that if CL is used the extra quantity of land is unlogged until year 60, then logged by RIL from year 60 onwards. The justification of scenario 2 is that pressure for logging will increase by year 60, but that RIL will then be the only acceptable means of logging primary forest. Then, over t_{60}-t_{120} it will be post-RIL forest with the same values for soil, water, wildlife, rattan and carbon as the same area under the RIL scenario. The following describes the assumptions used in scenario 2.

For a given amount of volume to be produced by RIL in scenario 2, it means that there have to be 136 ha of RIL for every 106 ha of CL logged because of the lower volume extracted per hectare. Therefore, for every 106 ha of CL forest that is logged, there would be 30 ha of unlogged forest, i.e. for each hectare of CL, there would be 30/106 ha (0.28 ha) of unlogged forest (hereinafter the spare area). This 0.28 ha will produce a value for benefit and cost due to the management for production as logged area: these additional values would be added to the CL per cubic metre values obtained in scenario 1. The assumptions for the CBA of this 0.28 ha are as follows:

A) Benefits:

a) There will be no logging at t_0, hence, no value for t_0 timber revenue or for $t_{0\text{-}60}$ carbon, soil or water values.
b) During $t_{0\text{-}60}$, there will be no variation in rattan (i.e. no harvesting) from the baseline primary forest values.
c) During $t_{0\text{-}60}$, there will be no variation (i.e. no harvesting) of wildlife from the baseline primary forest values.
d) Logging by RIL at t_{60} is calculated by multiplying RIL t_0 timber revenue adjusted by increase in timber prices at 2 % per year for 60 years by 30/106.
e) During $t_{60\text{-}120}$, soil values will be excluded because they are based on t_{120} timber harvest (into the third harvesting cycle) which lies outside the time frame of analysis.

f) During $t_{60\text{-}120}$, water values are calculated by multiplying the RIL $t_{0\text{-}60}$ water value by 30/106.

g) During $t_{60\text{-}120}$, harvesting of rattan from post-RIL logged forest is calculated by multiplying the RIL $t_{0\text{-}60}$ rattan value by 30/106.

h) During t_{60}-t_{120}, harvesting of wildlife from post-RIL logged forest is obtained by multiplying the RIL $t_{0\text{-}60}$ wildlife value by 30/106.

B) Costs:

a) No logging at t_0, hence no value to add for t_0 timber harvest cost

b) During $t_{0\text{-}60}$, there will be no variation of rattan from primary forest values.

c) During $t_{0\text{-}60}$, there will be no variation of wildlife from primary forest values.

d) Logging by RIL at t_{60} is calculated by multiplying the RIL t_0 timber harvest cost inflated by 2 % per year up to 60 years by 30/106.

e) During $t_{60\text{-}120}$, harvesting of rattan from post-RIL logged forest is obtained by multiplying RIL $t_{0\text{-}60}$ rattan harvest cost by 30/106.

f) During $t_{60\text{-}120}$, harvesting of wildlife from post-RIL logged forest is calculated by multiplying the RIL $t_{0\text{-}60}$ wildlife harvest cost by 30/106.

These per logged hectare RIL values are totalled and divided by 136 m^3 ha^{-1} to convert to values per cubic metre CL logged in t_0, and added to the CL values in Table 10.2.

10.2.4 Estimating the break-even carbon price

For the present study, the break-even price of carbon on a per hectare basis, including opportunity costs, is calculated by the following formula:

$$\frac{\text{[CL net benefit per hectare]} - \text{[RIL net benefit per hectare]}}{\text{[RIL carbon tonnes per hectare]} - \text{[CL carbon tonnes per hectare]}}$$

The carbon tonnes are defined as the mean carbon storage times years of storage based on the difference between primary forest and RIL/CL logged forests when there is no discounting, and on summed discounted flow with discounting. The calculations for the mean carbon storage and flows have been presented in chapter 5. The economic cost of carbon differs from the financial cost calculations in that the former includes the non-timber values or externalities.

To estimate carbon cost under the displaced logging scenarios (i.e. both scenario 1 and 2), the calculations are done on a per cubic metre basis as:

$$\frac{[\text{CL net benefit per } m^3] - [\text{RIL net benefit per } m^3]}{[\text{RIL carbon tonnes per } m^3] - [\text{CL carbon tonnes per } m^3]}$$

Carbon storage or flow per cubic metre for the RIL and CL forest has been calculated in chapter 5.

10.3 Results and discussion

10.3.1 Relative physical value of forest products and services

The consequences of conventional logging in Sabah which extracts 13 trees or 136 m^3 bigger than 60 cm DBH from a hectare of tropical forest leaves approximately 56 % of the original stem density bigger than 1 cm DBH in the forest (Table 10.1). The dipterocarps, the dominant timber species group in Sabah, comprised approximately 57 % of the original tree density. The proportion of ground area created for roads, skid trails and log landings was 17 % or 29.2 ha of the total logging area of 176 ha. These results are typical of mechanized logging in the South East Asian region (Fox, 1968; Johns, 1997), and are caused by two main areas of logging operations namely, felling and skidding operations.

When a tree of 60 cm DBH is felled, as in the case of Sabah, its mere trunk and large crown measuring 20-30 m in diameter will inevitably smother smaller trees in its path. The impact on the neighbouring trees is much greater if trees are felled without regard to falling direction. Felling damage is increased when a tree laden with lianes is cut. Lianes use trees as a trellis and intertwine themselves among the trees. When a tree that is laden with lianes falls, it pulls down neighbouring trees along with it.

However, much more serious logging damage is done with skidding operations or the removal of trees from the stump to the log landings. The bulldozer employed to extract timber is a powerful machine with 200 hp. Bulldozers can be extremely damaging to both trees and soils. Frequently, all vegetation and topsoil are bulldozed from extraction routes and an inexperienced bulldozer operator can create unnecessarily large openings for log landings and skid trails.

The degree and extent of logging disturbance are closely associated with the intensity of timber harvest. More timber extracted from an area means more felling gaps and ground openings to access these trees. The extraction intensity in Sabah is relatively high when compared with extraction levels in other tropical forest regions, e.g. only 30-50 $m^3\ ha^{-1}$ in the Para state of the Brazilian Amazon (Uhl and Vieira, 1989). Therefore, it is not surprising that logging disturbance to the forest in Sabah would be high, in particular, when logging is not adequately supervised.

Table 10.1 Relative physical value of forest values for an area of tropical forest in Sabah logged by RIL and CL

Forest values	RIL	CL	$\frac{\text{RIL-CL (\%)}}{\text{CL}}$
A. Timber			
A.1 Forest area (ha)			
+ Before logging	230 ha	176 ha	31%
+ Logged	128 ha	175 ha	-27%
A.2 Tree density (>1 cm DBH)			
+ Before logging (tree ha^{-1})	3,798 ± 101	4,382 ± 212	-13%
+ After logging (tree ha^{-1})	3,001 ± 131	2,463 ± 212	22%
A.3 Dipterocarps composition			
+ Before logging (tree ha^{-1})	522 ± 69	742 ± 100	-30%
+ After logging (tree ha^{-1})	388 ± 46	435 ± 49	-11%
A.4 Removals (extracted and killed)	797 trees ha^{-1}	1,920 trees ha^{-1}	-58%
A.5 Volume extracted (m^3 ha^{-1})			
At t0	106 m3 or 9 trees ha^{-1}	136 m^3 or 13 trees ha^{-1}	-22%
At t60	111 m^3 ha^{-1}	85 m^3 ha^{-1}	31%
A.6 Trees damaged (destroyed)	21 % of original stems	44 % of original stems	-52%
A.7 Forgone timber	44 % by area	None (0)	a
B. Carbon			
B.1 Mean carbon storage	-39.17 Mg ha^{-1}	-81.22 Mg C ha^{-1}	148%
B.2 Summed of carbon flow	0.6 Mg C ha^{-1}	-42 Mg C ha^{-1}	-101%
C. Soil			
C.1 Length (m)			
Skid trails	8.17 ± 0.37 m	34.83 ± 0.99 m	-77%
Roads	3.76 ± 0.53 m	4.67 ± 0.15 m	-11%
C.2 Area (ha)			
Skid trails	4.3 ± 0.2 ha	21.0 ± 0.8 ha	-80%
Log landings	0.7 ± 0.1 ha	1.7 ± 0.2 ha	-59%
Roads	4.3 ± 0.6 ha	6.5 ± 0.4 ha	-34%
D. Rattan (Stem length in m)			
D.1 Large cane	340 m	113 m	201%
D.2 Small cane	1,633 m	1,225 m	33%
E. Loss of water storage capacity (total mass of sediment)			
E.1 High yield	3,083 m^3 yr^{-1}	6,087 m^3 yr^{-1}	-49%
E.2 Low yield	2,614 m^3 yr^{-1}		-57%
F. Wildlife			
F.1 10 % culling	629 animals km^{-2}	543 animals km^{-2}	16%
F.2 40 % culling	2,514 animals km^{-2}	2,172 km^{-2}	16%

Note: The RIL-CL difference is for the purpose of ranking the forest values due to the effect of RIL in comprison with CL. However, some of the RIL-CL values are due to chance rather than the effect of logging treatments e.g. A.1 and A.2). The RIL-CL difference is calculated by: [[RIL-CL)/CL] x 100]. The sign of a number means higher or lower than CL values

Reducing damage seems to be an obvious aim from the ecological, silvicultural and economic standpoint. From the ecological perspective, minimising damage to the residual forest will prevent a sudden increase in the ambient temperature and a decrease in humidity in the forest. Such sudden changes in sunlight penetration to the forest floor may favour pioneer species but will also affect seedling growth response and may cause mortality to non-pioneer species (Borhan *et. al.,* 1984). Reducing damage level is also beneficial in terms of species richness since timber extraction in Sabah removes about 80 % of the 180 species of dipterocarps which dominate the canopy of the lowland forest. Where forest gaps are large, this promotes the colonisation of the climbing bamboo (*Dinocleo* spp.) and vine species (e.g. *Merrimia* spp.); both are known to compete with the commercial timber species (Putz, 1991). The climbing bamboos and vines use trees as a trellis to reach the canopy top and are known to 'strangle' or compete for light eventually slow tree growth. If close attention is paid to the biological constraints on forest regeneration, it is possible to log tropical rain forest without causing permanent ecosystem degeneration (Brown, 1998).

From Table 10.1, it is obvious that conventional logging in Sabah may not only lead to a decline in standing timber stocks but may also have wider environmental effects. The greatest impact of conventional logging is on the carbon storage benefit.

Not only is carbon sequestration benefit reduced following logging, the potential economic value of rattan was also affected (this was the second greatest impact of logging after carbon sequestration).

Several implications can be drawn from the above account. Firstly, different products and services can be obtained from an area of tropical forest in Sabah subject to conventional logging. This re-emphasises the fact that tropical forest is more than just trees (Poore, 1992). A forest planner or carbon policy maker must consider this non-timber value when planning, implementing or financing harvesting operations.

Secondly, selective logging does not bring about the disappearance of forests but removing even some of the trees obviously alters the ecosystem balance. In the context of this study, it not only changes the forest structure and ground conditions, but disrupts the flow of forest functions and services and hence, changes the relative importance of the timber and non-timber values.

Thirdly, non-timber effects include the loss of other consumptive uses (e.g. wildlife meat harvest, rattan), and the loss of ecological functions (e.g. carbon sequestration benefit, watershed protection). Too often, the non-timber benefits are treated as 'free goods' to be exploited at little or no costs. Logging companies often externalise these costs at the expense of taxpayers' money, e.g. public expenditure to remove sediments from dams. Consequently, loggers have little motivation to manage the forest to maximize the total benefits that a rain forest is capable of providing.

10.3.2 Relative physical performance of RIL and CL with respect to the range of forest values

Logging operations when properly carried out, such as RIL, can reduce the extent and degree of forest disturbances associated with CL. The performance of RIL relative to CL in terms of physical timber and non-timber values is summarised in Table 10.1. One obvious difference between RIL and CL techniques was that the level of incidental damage to residual trees was reduced by 52 %.

The reduction in tree damage was most apparent for trees in the diameter range between 20 and 50 cm DBH. These trees form the growing stock for future harvest and will determine the success of the silvicultural system practised in Sabah. Reducing damage to seedlings is a pre-requisite under the modified Malayan Uniform System which requires that healthy seedlings be present on the ground. Otherwise, the future forest may contain a low harvest volume making it uneconomical to harvest in the next cut unless rehabilitative measures are carried out such as by enrichment planting. Enrichment planting is a costly endeavour and it is much cheaper to reduce logging damage during harvesting. This approach has been emphasised by many, recognising that if properly carried out, the logging operation is an effective and inexpensive silvicultural tool compared with reforestation efforts (e.g. Cheah, 1991).

As a result of the reduction in logging damage, RIL forest yielded a higher standing stock in the second harvest at year 60 (RIL = 111 m^3 ha^{-1}; CL = 85 m^3 ha^{-1}, Table 10.1). This difference has important significance when the difference of 26 m^3 ha^{-1} is converted to monetary value especially with real price increases.

The impact of RIL on non-timber forest products such as rattan is also of significance. From this study, the rattan stocking in the RIL forest following logging was higher than that in CL forest by 200 % for the large diameter canes and 33 % for the small diameter canes (Table 10.1). The large difference in rattan stock in the two areas was attributed to the lesser extent of skid trails, log landing and roads in RIL, and secondly, the difference in the total area logged where nearly half of the RIL area remained unlogged due to the RIL guidelines.

By reducing damage, RIL logged forest can maintain its use for environmental services such as in carbon sequestration. Consequently, the loss of mean carbon storage in RIL was approximately half that of CL forest (RIL = -39.17 Mg C ha^{-1}; CL = -81.w2 Mg C ha^{-1}; Table 10.1). This difference was associated with the reduction of damage to residual timber in areas actually harvested. The carbon benefit is considerably higher if areas that were unlogged within the RIL units (by exclusion due to the RIL harvesting guidelines) are incorporated into the calculation (see values per management hectare in column B of Table 10.2).

A major concern about selective logging is its effects on forest soil. This study found that the extent and degree of soil disturbance was greatly reduced with RIL compared with CL. The total extent of skid trails, log landings and roads in RIL units occupied only 7 % of the total logged areas compared with 17 % in CL units (Table 10.1). Reducing the extent of these openings not only saves trees for the next harvest, but also reduces the capacity of soil erosion from these areas that would have both on-site and off-site adverse consequences.

One of the off-site consequences of soil erosion associated with logging is river sedimentation. The adoption of RIL had reduced sedimentation to slightly more than half (RIL = 3,083 m^3 yr^{-1}; CL = 6,087 m^3 yr^{-1}) over 60 years (Table 10.1). Reducing sedimentation load in rivers, among other things, means reducing loss of water storage capacity at the hydropower water-intake ponds downstream. The need to remove sediment reduces hydropower generation. The potential cost of loss of water capacity for hydropower generation in this case study is less for RIL than for CL.

Logging affects wildlife by changing the quality of the habitat e.g. particularly the supply of food as trees are removed or destroyed. Generally, wildlife can adapt to selective logging disturbance provided the degree and extent are within the wildlife's tolerance (Johns, 1997). This study found little difference in the density of ungulates and bearded pigs between RIL and CL logged forest (only 16 %; Table 10.1). This resulted in only a small difference in the consumptive use of wildlife for the study area.

The adoption of RIL techniques, however, left a substantial volume of timber that is forgone (44 % by area; Table 10.1). While this is a benefit from the conservation point of view (as it provides environmental services for carbon sequestration, maintenance of biodiversity etc), it means that total timber production from a given a tract of hill forest assigned for commercial use is reduced.

Clearly, there are a number of advantages in using RIL to harvest timber compared with CL techniques. A well-planned and executed logging operation reduces the adverse impacts on the timber and non-timber resources of the forest. Although it was evident that the performance of RIL was better than CL in respect of its physical impacts on some forest values, its acceptance would depend on the relative importance of these economic values, and the effect of discounting which is dealt with in the following section. From this study, the transition from CL to RIL techniques has imposed additional costs at the stand level, e.g. the forgone timber associated with RIL. The forgone area (mostly steep areas) is substantial and would have otherwise been logged by conventional practices. Although it makes sense to leave this area to avoid adverse long-term environmental effects if they were logged, it may be financially and socially inefficient. However, this cost can be partially offset by the long-term economic gains by using RIL techniques in terms of the higher timber stock at the second cut, and the on-site and off-site negative costs associated with conventional logging in Sabah.

10.3.3 Cost–benefit analysis

10.3.3.1 Cost–benefit analysis per hectare

The results of logging by RIL and CL per representative/management hectare, per logged hectare and per cubic metre are presented in Table 10.2 (columns B, C, and D, respectively). The key difference in the calculations between the per representative and per logged hectare was that the total costs and benefits were divided by different proportions of area. The per representative hectare included logged and unlogged areas within the whole management study areas. Conversely, column C and D's values were calculated per logged area. The values in the columns are expressed relative to unlogged primary forest values (note: carbon values are excluded in the rest of 10.3.3). The main findings of the CBA per logged hectare/cubic metre, and per representative hectare are as follows.

There were three important generalisations that could be noted in the three columns. Firstly, timber benefit dominated the CBA contributing over 90 % of the net benefit (excluding royalty). Secondly, the disbenefits attributed to soil and water values for RIL were lower for CL. Thirdly, the revenues and costs per representative hectare were lower than the per logged hectare values because the former included the opportunity costs of forgone timber, i.e. the portion of forest unlogged due to RIL harvesting guidelines.

10.3.3.1.1 Per logged hectare

The net economic benefit of a forest in Sabah that had been logged by RIL and CL was estimated to be worth RM28,714 ha^{-1} and RM29,715 ha^{-1}, respectively (Table 10.2).

Table 10.2 Undiscounted economic benefits and costs of RIL and CL techniques over two cutting cycles with the first over $t_{0\text{-}60}$ and the second over $t_{60\text{-}120}$

Forest values		A Whole management area (ha)		B Per represntative/ management (ha)		C Per logged hectare (ha)		D Per cubic metre (m^3)	
		RIL 230	CL 176	RIL 230	CL 176	RIL 129	CL 175	RIL 106	CL 136
1. Benefits:									
1 1 Timber	t_0	2,680,104.00	4,760,000.00	11,652 63	27,045.45	20,776.00	27,200.00	196.00	200.00
	t_{60}	9,450,540.00	9,648,275.00	41,089 30	54,819 74	73,260.00	55,133 00	691 13	405 39
1.2 Carbon	$t_{0\text{-}60}$	-39.17p X 129	-81.22p X175	-21.97p	-80.76p	-39.17p	-81 22p	-0.37p	-0.60p
	$t_{60\text{-}120}$	-39.17p X 129	-81.22p X175	(also see note x)		-39.17p	-81.22p	(also see note y)	
1.3 Rattan	$t_{0\text{-}60}$	-529,920.00	-724,064.00	-2,304 00	-4,114.00	-4,107.91	-4,137.51	-38.75	-30.42
	$t_{60\text{-}120}$	-529,920.00	-724,064.00	-2,304.00	-4,114.00	-4,107.91	-4,137.51	-38.75	-30.42
1.4 Wildlife	$t_{0\text{-}60}$	-15,870.00	-18,832.00	-69.00	-107.00	-123.02	-107.61	-1.16	-0.79
	$t_{60\text{-}120}$	-15,870.00	-18,832.00	-69.00	-107 00	-123.02	-107 61	-1 16	-0.79
1.5 Soil +	$t_{0\text{-}60}$	-229,719.33	-716,976.75	-998 78	-4,073 73	-1,780 77	-4,097 01	-16.80	-30 13
	$t_{60\text{-}120}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.6 Water	$t_{0\text{-}60}$	-65,904 81	-218,998.50	-286.54	-1,244 31	-510 89	-1,251.42	-4.82	-9.20
	$t_{60\text{-}120}$	-65,904.81	-218,998.50	-286.54	-1,244.31	-510.89	-1,251.42	-4 82	-9.20
Sub-total (excluding 1.2)		10,677,535.05	11,767,509 25	46,424 07	66,860.85	82,771.59	67,242 91	780.86	494 43
(excluding 1.1, 1.2)		*-1,453,108.95*	*-2,640,765.75*	-6,317.87	-15,004 35	-11,264 41	-15,090 09	-106.27	-110.96
2. Costs									
2.1 Timber	t_0	2,304,456.00	3,409,875 00	10,019.37	19,374.29	17,864.00	19,485.00	168.53	143 27
	t_{60}	6,264,111.00	5,351,325.00	27,235.27	30,405.26	48,559.00	30,579 00	458.10	224.85
2.2 Rattan	$t_{0\text{-}60}$	-229,770 00	-313,984.00	-999 00	-1,784.00	-1,781.16	-1,794 19	-16.80	-13.19
	$t_{60\text{-}120}$	-229,770.00	-313,984 00	-999.00	-1,784.00	-1,781.16	-1,794.19	-16.80	-13.19
2.3 Wildlife	$t_{0\text{-}60}$	-7,944.20	-9,423 04	-34 54	-53.54	-61.58	-53.85	-0.58	-0.40
	$t_{60\text{-}120}$	-7,944.20	-9,423.04	-34 54	-53.54	-61 58	-53 85	-0 58	-0.40
Sub-total		8,093,138.60	8,114,385 92	35,187.56	46,104.47	62,737.51	46,367.92	591.86	340.94
(excluding 2.1)		*-475,428.40*	*-646,814.08*	-2,067.08	-3,675 08	-3,685 49	-3,696 08	-34.77	-27.18
3. Net benefit		2,584,396.45	3,653,123.33	11,236.51	20,756.38	20,034 08	20,874 99	189.00	153 49
(excluding 1.1, 1.2, 2.1)		*-977,680.55*	*-1,993,951.67*	-4,250.79	-11,329.27	-7,578 92	-11,394 01	-71.50	-83.78
Add log royalty*									
	t_0	*546,960.00*	*952,000.00*	*2,378.09*	*5,409.09*	*4,240.00*	*5,440.00*	*40.00*	*40 00*
	t_{60}	*572,760.00*	*595,000 00*	*2,490.26*	*3,380.68*	*4,440.00*	*3,400.00*	*41.89*	*25.00*
4 Total net benefit *(excluding 1.2)*		3,704,116.45	5,200,123.33	16,104 85	29,546.16	28,714.08	29,714 99	270.89	218.49

A Whole study area: revenues and costs per logged ha (item c) multiplied by 129 ha or 175 ha for RIL and CL, respectively
B Per unit representative hectare - this is (C) multiplying by 129/230 ha or 175/176 ha for RIL and CL, respectively
C Per logged unit - these values were from chapters 4-9
D Per m^3 - this is (C) divided by 106 or 136 m^3 ha^{-1} for RIL and CL, respectively
1.2 Carbon values for RIL and CL are calculated by taking the net difference between the mean carbon storage of primary forest and logged forest, respectively, and multiplied by the annual price per tonne (denoted by p) approach based on C. Price (pers.comm.) Since the objective is to obtain a break-even price for carbon, the economic value of carbon is not calculated here
* Log royalty is at RM40 m^{-3}
x Carbon price per representative hectare: RIL = -39.17p multiplied by 129/230 ha; CL = -81.22p multiplied by 175/176 ha
y Carbon price per cubic metre: RIL = -39.17p divided by 106 m^3, CL = -81.22p divided by 136 m^3
\+ Soil relates to opportunity costs of timber logged at year 120, so is excluded (otherwise there would be three cycles of timber harvest)

These values represent the undiscounted sum for five forest values namely, timber, soil, rattan, water and wildlife over two harvest cycles (t_0-t_{120}).

Timber benefit dominated the CBA of RIL and CL contributing 77-80 % of revenue. The combined t_0 and t_{60} timber revenues from RIL were higher than CL , in particular, for the t_{60} revenue due to higher harvest yield. However, RIL's net timber benefit was reduced after taking off the higher extraction costs compared with CL. Overall, the net timber benefit of RIL was similar to CL.

Among the non-timber forest values, rattan was the most important economic product which generated the highest economic return. However, following the assumptions used in the analysis, RIL had the same rattan revenues per logged area as to CL. The economic value of wildlife harvest was the least important in this analysis because of the small difference in wildlife yield between logged and unlogged forest, and RIL-CL differences were slight. The disbenefits of soil and water values in RIL were half those of CL, and their overall contribution in money terms offset some of the RIL's high timber extraction costs. The non-timber values had little impact on the overall CBA.

With a 2 % discount rate, the net economic returns for RIL and CL reduced to RM8,577 and RM11,996 ha^{-1} over two harvest cycles of 120 years (Table 10.3). These amounts were only 30 % and 40 % of the undiscounted net benefits of RM28,714 ha^{-1} and RM29,715, respectively. At a higher discount rate of 6 %, the economic returns represented 11 % and 26 % of the undiscounted net benefit for RIL and CL, respectively. More drastic reduction was evident when the discount rate was raised to 10 %; resulting in only 9 % and 25 % of the undiscounted net benefit for RIL and CL, respectively. Higher discount rates reduced the economic return of RIL much more than CL because CL's main benefit was the immediate t_0 timber revenue, whereas RIL's were the more distant non-timber benefits ($t_{0\text{-}120}$) and t_{60} timber revenues which are relatively unimportant by discounting.

10.3.3.1.2 Per representative hectare

The total net benefits per representative hectare logged by RIL and CL were RM16,105 ha^{-1} and RM29,546 ha^{-1}, respectively without discounting (Table 10.2). The difference of RM13,441 ha^{-1} or 45 % of the CL was entirely due to RIL's t_0 and t_{60} timber benefit from all forest values, in particular, the timber benefit. The difference of RM13,441 ha^{-1} chiefly represents the opportunity cost of forgone timber that could not be harvested in RIL due to the RIL guidelines. This opportunity cost was correlated with the proportion of forest area that was left unlogged by RIL. For instance, the total RIL timber benefit per representative hectare of management unit (RM52,742 ha^{-1} for t_0 and t_{60}) was

Table 10.3 Net benefit values per logged area (RM ha^{-1}) of timber and non-timber values (excluding carbon) for RIL and CL units over two harvesting cycles with first at $t_{0\text{-}60}$ and the second at $t_{60\text{-}120}$

Discount rates (%)	Economic values for t0-60						Economic values for t60-120						Total	
	Timber t_0	Soil $t_{0\text{-}60}$	Rattan $t_{0\text{-}60}$	Water $t_{0\text{-}60}$	Wildlife $t_{0\text{-}60}$	Sub-total $t_{0\text{-}60}$	Timber t_{60}	Soil* $t_{60\text{-}120}$	Rattan $t_{60\text{-}120}$	Water $t_{60\text{-}120}$	Wildlife $t_{60\text{-}120}$	Sub-total $t_{60\text{-}120}$	per ha $t_{0\text{-}120}$	per m^3
A) RIL														
2%	2,912.00	-543.13	-682.00	-310.24	-19.71	1,356.92	7,528.00	0.00	-207.86	-94.55	-6.01	7,219.58	8,576.50	80.91
4%	2,912.00	-169.17	-398.00	-209.91	-12.66	2,122.26	2,348.00	0.00	-37.83	-19.95	-1.20	2,289.01	4,411.27	41.62
6%	2,912.00	-53.42	-253.00	-154.41	-8.95	2,442.22	749.00	0.00	-7.67	-4.68	-0.27	736.38	3,178.60	29.99
8%	2,912.00	-17.81	-172.00	-120.78	-6.79	2,594.62	244.00	0.00	-1.70	-1.19	-0.07	241.04	2,835.66	26.75
10%	2,912.00	-5.34	-123.00	-98.74	-5.43	2,679.49	81.00	0.00	-0.40	-0.32	-0.02	80.25	2,759.74	26.04
B) CL														
2%	7,715.00	-1,249.59	-1,216.00	-249.31	-31.55	4,968.55	7,484.00	0.00	-370.61	-75.98	-9.62	7,027.79	11,996.34	88.21
4%	7,715.00	-389.22	-709.00	-168.68	-20.40	6,427.70	2,334.00	0.00	-67.40	-16.03	-1.94	2,248.63	8,676.33	63.80
6%	7,715.00	-122.91	-451.00	-124.09	-14.25	7,002.75	744.00	0.00	-13.67	-3.76	-0.43	726.13	7,728.88	56.83
8%	7,715.00	-40.97	-307.00	-97.06	-10.59	7,259.38	242.00	0.00	-3.03	-0.96	-0.10	237.90	7,497.28	55.13
10%	7,715.00	-12.29	-219.00	-79.35	-8.24	7,396.12	81.00	0.00	-0.72	-0.26	-0.03	79.99	7,476.11	54.97
C) RIL-CL														
2%	-4803.00	706.46	534.00	-60.93	11.84	-3611.63	44.00	0.00	162.75	-18.57	3.61	191.79	-3,419.84	-7.30
4%	-4803.00	220.05	311.00	-41.23	7.74	-4305.44	14.00	0.00	29.56	-3.92	0.74	40.38	-4,265.06	-22.18
6%	-4803.00	69.49	198.00	-30.32	5.30	-4560.53	5.00	0.00	6.00	-0.92	0.16	10.24	-4,550.29	-26.84
8%	-4803.00	23.16	135.00	-23.72	3.80	-4664.76	2.00	0.00	1.33	-0.23	0.04	3.14	-4,661.62	-28.38
10%	-4803.00	6.95	96.00	-19.39	2.81	-4716.63	0.00	0.00	0.32	-0.06	0.01	0.26	-4,716.37	-28.94

* This relates to opportunity costs of timber logged at year 120, so is excluded (otherwise there would be three cycles of timber harvest)

approximately half that per logged hectare (RM94,036 ha^{-1}), whereas for CL the difference was slight.

With a 2 % discount rate, the total net benefit for RIL and CL had similar levels of decline as per logged area (Table 10.4). Basically, discounting makes the distant timber and non-timber benefits less important relative to the immediate logging revenues.

10.3.3.2 Cost–benefit analysis without and with displaced logging

The undiscounted net economic benefit per cubic metre of timber harvested at t_0 with RIL amounted to RM271 m^3 (Table 10.2). Under scenario 1 for CL, without discounting displaced logging of the additional forest area unused in comparison with RIL, the net benefit would be RM219 m^{-3} or 19 % lower than with RIL (Table 10.2 column D).

For CL, however, the inclusion of the additional economic benefit from logging of the displaced 0.28 ha compared with RIL, under scenario 2, would increase the overall CL net benefit by approximately RM13 m^{-3} or 6 % with no discountng (Table 10.5). This means that the total net benefit for CL amounted to RM231 m^{-3} under scenario 2, but this is still lower than RIL.

Discounting at rates of 2 % and above reverses the position under both scenarios, with RIL now having lower value than CL (Table 10.3). This is because RIL's advantage in t_{60} timber revenues and non-timber benefits become relatively unimportant.

Under scenario 2, with discounting, the additional economic benefit from the 0.28 ha added little value to CL's total net benefit because the distant timber (at t_{60}) and non-timber benefits ($t_{60\text{-}120}$) were reduced (Table 10.5). With higher discount rates of 6 % and above, the net economic return for the additional area was very low (less than RM1 m^{-3}).

10.3.4 Break-even carbon prices

10.3.4.1 Scenario 1: mean carbon storage approach

Tables 10.6 and 10.7 show values for the profit made per tonne of carbon lost by RIL and CL, and the cost per tonne of replacing CL by RIL. With no discounting using the mean carbon storage method (Table 10.6), the carbon price to replace CL with RIL would be RM0.20 per carbon tonne-year, on the per hectare logged basis. Conversely, the carbon price to replace RIL on a representative hectare was estimated to be RM1.91 per carbon tonne-year. The higher carbon price for representative hectare compared with the price per logged hectare was attributed mainly to the opportunity costs of forgone timber in the

Table 10.4 Net benefit values per representative/management area (RM ha^{-1}) of timber and non-timber values (excluding carbon) for RIL and CL units over two harvesting cycles with the first at t_{0-60} and the second at t_{60-120}

Discount rates (%)	Economic values for t_{0-60}: Timber t_0	Soil t_{0-60}	Rattan t_{0-60}	Water t_{0-60}	Wildlife t_{0-60}	Sub-total t_{0-60}	Economic values for t_{60-120}: Timber t_{60}	Soil* t_{60-120}	Rattan t_{60-120}	Water t_{60-120}	Wildlife t_{60-120}	Sub-total t_{60-120}	Total per ha t_{0-120}
A) RIL													
2%	1,633.25	-304.63	-382.51	-174.00	-11.05	761.06	4,222.23	0.00	-65.39	-29.74	-1.89	4,125.20	4,886.26
4%	1,633.25	-94.88	-223.23	-117.73	-7.10	1,190.31	1,316.92	0.00	-11.90	-6.28	-0.38	1,298.36	2,488.68
6%	1,633.25	-29.96	-141.90	-86.60	-5.02	1,369.77	420.09	0.00	-2.41	-1.47	-0.09	416.12	1,785.89
8%	1,633.25	-9.99	-96.47	-67.74	-3.81	1,455.24	136.85	0.00	-0.53	-0.38	-0.02	135.92	1,591.16
10%	1,633.25	-3.00	-68.99	-55.38	-3.05	1,502.84	45.43	0.00	-0.13	-0.10	-0.01	45.20	1,548.04
B) CL													
2%	7,671.16	-1,242.49	-1,209.09	-247.89	-31.37	4,940.32	7,441.48	0.00	-366.41	-75.12	-9.51	6,990.43	11,930.75
4%	7,671.16	-387.01	-704.97	-167.72	-20.28	6,391.18	2,320.74	0.00	-66.63	-15.85	-1.92	2,236.33	8,627.51
6%	7,671.16	-122.21	-448.44	-123.38	-14.17	6,962.96	739.77	0.00	-13.52	-3.72	-0.43	722.11	7,685.07
8%	7,671.16	-40.74	-305.26	-96.51	-10.53	7,218.13	240.63	0.00	-3.00	-0.95	-0.10	236.58	7,454.71
10%	7,671.16	-12.22	-217.76	-78.90	-8.19	7,354.10	80.54	0.00	-0.71	-0.26	-0.03	79.54	7,433.64
C) RIL-CL													
2%	-6037.91	937.86	826.58	73.89	20.32	-4179.26	-3,219.25	0.00	301.03	45.38	7.62	-2,865.23	-7,044.49
4%	-6037.91	292.13	481.75	49.99	13.18	-5200.87	-1,003.82	0.00	54.73	9.58	1.54	-937.97	-6,138.84
6%	-6037.91	92.25	306.54	36.78	9.15	-5593.19	-319.68	0.00	11.10	2.25	0.34	-305.99	-5,899.18
8%	-6037.91	30.75	208.79	28.77	6.72	-5762.89	-103.77	0.00	2.46	0.57	0.08	-100.65	-5,863.55
10%	-6037.91	9.23	148.77	23.52	5.15	-5851.25	-35.11	0.00	0.58	0.16	0.02	-34.35	-5,885.60

* This relates to opportunity costs of timber logged at year 120, so is excluded (otherwise there would be three cycles of timber harvest)

Table 10.5 Benefit-cost analysis of displaced logging in which the scenario is that with CL the additional area (0.28 ha) is logged by RIL at t_{60} and non-timber values are realised $t_{60\text{-}120}$

Forest values		Per logged hectare (ha) 1 ha	Per hectare (ha) logged at t_0 0 283 ha	Per cubic metre (m^3) logged at t_0 136
1. Benefits:				
1 1 Timber	t_0	0 00	0.00	0 00
	t_{60}	68,166.70	19,292.46	141 86
1 2 Carbon	$t_{0\text{-}60}$	0.00	0 00	-
	$t_{60\text{-}120}$	-39.17p	-11 09p (see note x)	-0 082p (see note y)
1 3 Rattan	$t_{0\text{-}60}$	0 00	0.00	0 00
	$t_{60\text{-}120}$	-4,107.91	-1,162.62	-8 55
1.4 Wildlife	$t_{0\text{-}60}$	0.00	0 00	0.00
	$t_{60\text{-}120}$	-123.02	-34.82	-0.26
1 5 Soil	$t_{0\text{-}60}$	0.00	0.00	0 00
	$t_{60\text{-}120}$	0.00	0.00	0.00
1.6 Water	$t_{0\text{-}60}$	-510.89	-144 59	-1 06
	$t_{60\text{-}120}$	-510.89	-144 59	-1 06
Sub-total			17,805 84	130 93
2. Costs				
2.1 Timber	t_0	0 00	0.00	0 00
	t_{60}	58,612.33	16,588.40	121.97
2.2 Rattan	$t_{0\text{-}60}$	0.00	0 00	0.00
	$t_{60\text{-}120}$	-1,781.16	-504.10	-3 71
2.3 Wildlife	$t_{0\text{-}60}$	0.00	0 00	0.00
	$t_{60\text{-}120}$	-61.58	-17 43	-0.13
Sub-total		56,769 59	16,066.87	118.14
3. Net total benefit		0 %	1,738.98	12 79
		2 %	530 39	3 90
		4 %	165.20	1 21
		6 %	52.17	0.38
		8 %	17.39	0.13
		10 %	5 22	0 04

Management assumptions

1 Benefits
a) No logging at t0 or for t0-60 carbon, soil or water
b) t0-60 no harvesting of rattan from primary forest· 30/106 x zero value (primary forest)
c) t0-60 no harvesting of wildlife from primary forest· 30/106 x zero value (primary forest)
d) Logging by RIL at t60: calculated by 30/106 x t_0 timber revenue, adjusted for price increase (RM20,776 x (1.02)^60 for RIL)
e) t60-120 carbon values: 30/106 x value per logged ha
f) t60-120 harvesting of rattan from post-RIL logged forest. 30/106 x (RIL t60-120 rattan value per logged ha [=-RM4108 undiscounted])
g) t60-120 harvesting of wildlife from post-RIL logged forest: 30/106 x (RIL t60-120 wildlife value per logged ha [=-RM123.02 undiscounted])
h) t60-120 soil values: no value to add because they are based on t120 timber harvest which is excluded from the analysis
i) t60-120 water values: 30/106 x (RIL t60-120 water value per logged ha [=-RM510 89 undiscounted])

2 Costs
a) No logging at t0: no value to add for t0 timber harvest cost
b) t0-60 no harvesting of rattan from primary forest: 30/106 x zero value per (primary forest)
c) t0-60 no harvesting of wildlife from primary forest. 30/106 x zero value (primary forest)
d) Logging by RIL at t60: calculated by 30/106 x t0 harvest cost adjusted for cost increase (t0 = RM17,864 x (1 02)^60 for RIL)
e) t60-120 harvesting of rattan from post-RIL logged forest 30/106 x (RIL t60-120 rattan value per logged ha [=-1781 undiscounted])
f) t60-120 harvesting of wildlife from post-RIL logged forest 30/106 x (RIL t60-120 wildlife value per logged ha [=-61 58undiscounted])

x This is calculated by multiplying -39.17 x (30/106 ha)
y This is calculated by multiplying [-39 17 x (30/106 ha)]/136 m^3/ha

Table 10.6 Calculations for break-even carbon prices for RIL by the mean carbon storage and carbon flow approaches for scenario 1

		Per representative/ management hectare (ha)			Per logged hectare (ha) (ha)			Per cubic metre (m3)		
A) Net profit (RM)		RIL	CL	CL-RIL	RIL	CL	CL-RIL	RIL	CL	CL-RIL
A.1 Timber benef	0%	20,355.64	40,875.43	20,519.79	36,293.00	41,109.00	4,816.00	342.39	302.27	-40.12
	2%	5,855.48	15,112.64	9,257.16	10,440.00	15,199.00	4,759.00	98.49	111.76	13.27
	4%	2,950.17	9,991.90	7,041.73	5,260.00	10,049.00	4,789.00	49.62	73.89	24.27
	6%	2,053.34	8,410.94	6,357.59	3,661.00	8,459.00	4,798.00	34.54	62.20	27.66
	8%	1,770.10	7,911.79	6,141.69	3,156.00	7,957.00	4,801.00	29.77	58.51	28.73
	10%	1,678.68	7,751.70	6,073.02	2,993.00	7,796.00	4,803.00	28.24	57.32	29.09
A.2 Non-timber benefit		-4,250.79	-11,329.27	-7,078.48	-7,578.92	-11,394.01	-3,815.09	-71.50	-83.78	-12.28
	2%	-1,045.18	-3,184.46	-2,139.28	-1,863.50	-3,202.66	-1,339.16	-17.58	-23.55	-5.97
	4%	-476.03	-1,364.87	-888.84	-848.73	-1,372.67	-523.94	-8.00	-10.09	-2.09
	6%	-270.56	-725.97	-455.41	-482.40	-730.12	-247.72	-4.55	-5.37	-0.82
	8%	-179.67	-457.11	-277.44	-320.34	-459.72	-139.38	-3.02	-3.38	-0.35
	10%	-130.83	-318.07	-187.24	-233.26	-319.89	-86.63	-2.20	-2.35	-0.15
A.3 Total (Timber+non-timber)		16,104.85	29,546.16	13,441.31	28,714.08	29,714.99	1,000.91	270.89	218.49	-52.40
	2%	4,810.30	11,928.18	7,117.88	8,576.50	11,996.34	3,419.84	80.91	88.21	7.30
	4%	2,474.15	8,627.03	6,152.89	4,411.27	8,676.33	4,265.06	41.62	63.80	22.18
	6%	1,782.78	7,684.97	5,902.19	3,178.60	7,728.88	4,550.28	29.99	56.83	26.84
	8%	1,590.44	7,454.68	5,864.25	2,835.66	7,497.28	4,661.62	26.75	55.13	28.38
	10%	1,547.85	7,433.63	5,885.78	2,759.74	7,476.11	4,716.37	26.04	54.97	28.94
B) Carbon statistics										
				RIL-CL			RIL-CL			RIL-CL
B.1 Mean carbon storage x 12		-2,636.31	-9,691.02	7,054.71	-4,700.40	-9,746.40	5,046.00	-44.34	-71.66	27.32
B.2 Carbon flows	2% (t0-120)	-21.73	-91.44	69.71	-38.75	-91.96	53.22	-0.37	-0.68	0.31
	4% (t0-120)	-24.90	-85.92	61.02	-44.39	-86.41	42.02	-0.42	-0.64	0.22
	6% (t0-120)	-25.26	-81.58	56.32	-45.04	-82.05	37.01	-0.42	-0.60	0.18
	8% (t0-120)	-24.84	-77.82	52.98	-44.29	-78.26	33.98	-0.42	-0.58	0.16
	10% (t0-12(	-24.05	-74.11	50.06	-42.88	-74.53	31.65	-0.40	-0.55	0.14
C) Carbon pricing										
C.1 Mean carbon storage x 120 yrs (RM tCy)										RIL-CL
C.1 Timber benefit		-7.72	-4.22	2.91	-7.72	-4.22	0.95	-7.72	-4.22	-1.47
C.2 Non-timber benefit		1.61	1.17	-1.00	1.61	1.17	-0.76	1.61	1.17	-0.45
C.3 Total		-6.11	-3.05	1.91	-6.11	-3.05	0.20	-6.11	-3.05	-1.92
C.2 Carbon flows (RM tC^{-1})										
										RIL-CL
Timber	2%	269.45	165.27	132.80	269.45	165.27	89.42	269.45	165.27	42.70
	4%	118.49	116.30	115.40	118.49	116.30	113.98	118.49	116.30	112.06
	6%	81.28	103.10	112.88	81 28	103.10	129.65	81.28	103.10	155.06
	8%	71.26	101.67	115.92	71.26	101.67	141.30	71.26	101.67	182.25
	10%	69.80	104.60	121.31	69.80	104.60	151.73	69.80	104.60	202.67
Non-timber	2%	48.10	34.83	-30.69	48.10	34.83	-25.16	48.10	34.82	-19.21
	4%	19.12	15.89	-14.57	19.12	15.89	-12.47	19.11	15.88	-9.64
	6%	10.71	8.90	-8.09	10.71	8.90	-6.69	10.70	8.90	-4.60
	8%	7.23	5.87	-5.24	7.23	5.87	-4.10	7.24	5.87	-2.24
	10%	5.44	4.29	-3.74	5.44	4.29	-2.74	5.43	4.29	-1.03
Total	2%	221.36	130.45	102.11	221.36	130.45	64.26	221.35	130.45	23.50
	4%	-99.37	100.41	100.84	99.37	100.41	101.51	99.38	100.42	102.42
	6%	70.57	94.20	104.80	70.57	94.20	122.95	70.58	94.20	150.46
	8%	64.03	95.79	110.69	64.03	95.79	137.20	64.02	95.80	180.01
	10%	64.36	100.31	117.57	64.36	100.31	148.99	64.37	100.30	201.64

A The net profits are sourced from this chapter - Tables 10.2, 10.3 and 10.4

B The carbon statistics are sourced from chapter 5 - appendix 5.1. The mean carbon stock (t0-60) for RIL and CL per logged hectare were -39.17 and -81.22 Mg C ha^{-1}, respectively. The t60-120 values were added to the t0-t60 values after discounting

The unit for mean carbon storage is tonne-years while for carbon flows, it is discounted tonne

C Carbon break-even price calculations are described in section 10.2.3 and 10.2.4 of this chapter.

The per cubic metre break-even price is obtained by dividing by 106 and 136 m^3 ha^{-1} for CL and RIL, respectively

Table 10 7 Calculations for break-even carbon prices for RIL by the mean carbon storage and carbon flow approaches on a per cubic on a per cubic metre basis for scenario 2

		RIL	CL	CL-RIL
A) Net profit (RM)				
A.1 Timber benefit		342.39	322.15	-20 24
A.2 Non-timber benefit		-71 50	-90 87	-19 37
A.3 Total (Timber + non-timber		270.89	231.28	-39 61
	2%	80.91	92.11	11 20
	4%	41.62	65 01	23 39
	6%	29.99	57 21	27.22
	8%	26 75	55.26	28.51
	10%	26.04	55.01	28 97
B) Carbon statistics				
				RIL-CL
B 1 Mean carbon storage (120		-44.34	-76.56	32.21
B.2 Carbon flows	2% (t0-120)	-0 37	-0.70	0 33
	4% (t0-120)	-0 42	-0.64	0 22
	6% (t0-120)	-0.42	-0.61	0.18
	8% (t0-120)	-0.42	-0 58	0 16
	10% (t0-120)	-0.40	-0 55	0 14
C) Carbon pricing				
C 1 Mean carbon storage (RM tCy)				RIL-CL
C.1 Timber benefit		-7 72	-4 21	-0.63
C.2 Non-timber benefit		1.61	1 19	-0 60
C.3 Total		-6.11	-3.02	-1 23
C.2 Carbon flows (RM tC)				
				RIL-CL
Total	2%	-221 35	-132.52	33 99
	4%	-99.38	-101 05	104 15
	6%	-70 58	-94.40	150 29
	8%	-64 02	-95 87	179.79
	10%	-64.37	-100.33	201 47

A RIL: values from Table 10.6 (per m^3 column)
CL: values from Table 10.6 (per m^3 column) plus values from Table 10.5 (item 3)

B.1 RIL: the $t_{0\text{-}60}$ values is -39.17 tC (Appendix 5.1) plus $t_{60\text{-}120}$ values based on $t_{0\text{-}60}$ values discounted for another 60 years
CL: $t_{0\text{-}60}$ values is -81 22 tC (Appendix 5.1) plus $t_{60\text{-}120}$ based on $t_{0\text{-}60}$ values discounted for another 60 years

B.2 Carbon flows for RIL: values from Table 10 6 (item B 2 from per m^3 column)
Carbon flows for CL. values from Table 10 6 (item B.2 per m^3 column) plus RIL $t_{0\text{-}60}$ carbon flows per logged area (from Appendix 5 1 at each discount rate), discounted for an extra 60 years, multiplied by 0.283 ha and divided by 136 m3/ha
E.g. At 2 % discount rate: (-0 68) + (-29.69 x 0.305) x (0.283/136) = 0.698

C Carbon pricing calculations are described in section 10.2.2. and 10.2 3 of this chapter. However, for the carbon pricing caclulated using carbon flow, the flow was discounted by an extra 60 years since this will only come in at the second cycle

RIL area. Although mean carbon storage in RIL was also different, this effect was less significant than the opportunity costs.

The carbon price per cubic metre under scenario 1 was estimated to be a negative RM1.92 per carbon tonne-year because RIL is more profitable as well as losing less carbon. This is due to the t_{60} harvest, when RIL had higher yields compared with CL (RIL = 111 m^3 ha^{-1}; CL = 85 m^3 ha^{-1}).

10.3.4.2 Scenario 1: discounted carbon flows approach

Per logged hectare, the estimated carbon price to replace CL with RIL using the flow approach ranged from RM64 to RM149 tC^{-1} (Table 10.6). At higher discount rates, the loss of net benefit from RIL compared with CL becomes greater, while the discounted carbon flows become relatively smaller.

Per representative hectare, the break-even carbon price to replace CL with RIL at a low discount rate (2 %) increased to RM102 tC^{-1} compared with RM64 tC^{-1} per logged hectare. At higher discount rates, the carbon prices are similar because the main factors (opportunity costs of timber and loss of carbon) both happen in the short term.

The carbon price per cubic metre to replace CL with RIL under scenario 1, however, was strongly affected by discount rates. At a 2 % discount rate, the carbon price was estimated to be RM24 tC^{-1}. The price increased significantly to RM202 tC^{-1} at 10 % discount rate. The reason the per cubic metre values changed so much was that the t_{60} values dominate at low, but not high discount rates.

10.3.4.3 Scenario 2

The carbon price to replace CL with RIL under scenario 2 after including the additional benefit and carbon cost from the t_{60} logging of the 0.28 ha originally unlogged by CL was a negative RM1.23 per carbon tonne-year with no discounting calculated by the mean carbon storage approach (Table 10.7).

By the carbon flow approach, carbon prices ranged from RM34 to RM201 tC^{-1} (Table 10.6). At a 2 % discount rate, the carbon price of RM34 was 38 % higher than estimate obtained for scenario 1 (RM24 tC). At discount rates higher than 4 %, the carbon prices for scenario 2 were very similar to those obtained for scenario 1 because the distant benefits were made less significant.

10.4 Summary

This chapter dealth with the cost and benefit of RIL and CL with the aim to estimate a break-even carbon price for RIL. To perform the CBA, the extent which RIL and CL altered the timber and non-timber values was first examined. Clearly, there were a number of advantages in using RIL to harvest timber compared with CL as identified in Table 10.1. On the basis of this impact assessment, a CBA was performed over two harvest cycles of 120 years for RIL and CL. The CBA for each of the forest values were expressed as the differences between logged and unlogged forest values. As an addition to the main CBA, an estimate of the costs of forgone timber harvest was made assuming that RIL had to log a larger area of forest spilling over to another area. Three levels of analysis was presented: per representative hectare, per logged hectare and per cubic metre of wood produced. RIL could only be justified on a per cubic metre basis at a zero discount rate. On a per hectare basis, the CBA was dominated by the opportunity cost of forgone timber due to the RIL guidelines. One option to retain RIL would be to subsidise its cost through carbon benefit. This study found that the carbon break-even price to replace CL with RIL varied with the valuation methods (i.e. mean carbon storage or flow) and the level of analysis (i.e. per logged hectare, per representative hectare or per cubic metre). With the mean carbon storage method (zero discounting), the break-even carbon price per logged hectare was RM0.20 per carbon tonne-year, and per representative hectare was RM1.92 per carbon tonne-year. On a per cubic metre basis, the carbon price was a negative RM1.92 per carbon tonne-year because RIL was more profitable as well as loosing less carbon. With the carbon flow method, the lump sum price to replace CL with RIL ranged from RM64 to RM202 tC^{-1}. With the flow method, a high discount rate yielded a high carbon price because it reduced the distant cash flow and produced a smaller summed flow compared with flow with low discount rate.

Chapter 11: Conclusions and recommendations

The key findings of this research are summarised as follows:

1 RIL costs money, and costs a lot, under some assumptions and constraints (e.g. when there is a physical limit on total land availability). RIL costs more than the "RIL investment costs" that have been previously used (at RM6.20 m^{-3} in chapter 4). However, the cost depends on the level of analysis (per representative hectare, per logged hectare, per cubic metre, and maybe depending on whether scenario one or scenario two is followed on the "spare" CL area – the area equivalent to the displaced logging area in RIL which is required to make up the volume). It also depends on the discount rate in a possibly unexpected way (negative or low cost at zero discount). There are options to reduce the cost of RIL but they also make RIL less effective in achieving its objectives.

2 (a) Non-market elements other than carbon in the cost–benefit analysis are relatively unimportant.

(b) However, some of these elements leave out some aspects of value (existence value of wildlife), or are only quantified speculatively (hydroelectric losses).

It is (b), not (a), that makes a case for more effort in quantification; the objective of quantification is not to force the non-market elements to become more important, but to give them more appropriate weight. For example, the hydroelectric costs might in reality be smaller than estimated in this study because it was a demonstration of a method of evaluating off-site costs rather than a deeply researched case study.

3 As a consequence of the findings presented, carbon prices are also very variable, ranging from negative prices, through prices quite comparable with other results, to very high prices. The per representative hectare prices would be most realistic for Innoprise Corporation Sdn Bhd because of the impending land constraint to compensate for any reduction in timber volume if RIL was adopted to harvest timber. Using the mean carbon storage approach, the annual carbon price to break-even would be approximately RM2.00 per tonne-year of carbon. Alternatively, the carbon flow approach would cost between RM102 and RM118 tC with discount rates ranging from 2-10 %.

These values are higher than are usually suggested for carbon prices, but RIL may just be a very expensive way of locking up carbon. Comparisons with other costs for offset and damage avoided approaches would be valid only at the same discount rate as used by the author of the figures. Nevertheless, some published values are given below.

Enrichment planting of logged forest as a carbon offset technique has been implemented in Sabah (e.g. Moura-Costa, 1995), and the estimated cost of all tropical forest management is in the range of RM2.50-57.50 tC^{-1} (US$1-36 tC^{-1}).

The cost of afforestation options was between RM11 and RM12.50 [US$4.3-5 tC^{-1}] (Sedjo and Solomon, 1989 and Nordhaus, 1991), and for reforestation options was between RM5 and RM65 [US$2-26 tC^{-1}] (Shroeder *et. al.*, 1993). The cost estimate presented in Sedjo and Solomon (1989) was based on a 40-year period with a discount rate of 5 %.

The cost per tonne of carbon of avoiding carbon emissions from deforestation in Brazil, Cote d'Ivore and Indonesia was estimated to be RM6 (US$2.30), RM20 (US$8) and RM38 (US$15), respectively (Darmstadter and Plantinga, 1991). The methods of valuation were based on the opportunity costs for agricultural and logging production.

Nordhaus (1991), Cline (1992) and Fankhauser (1995) have produced estimates of damage-avoidance cost of global warming by calculating both damage and damage avoidance cost, and express this as a percentage of gross world product (GWP). Nordhaus's estimate suggested a damage equal to some 0.25 % of GWP as a result of CO_2 doubling, while Cline's and Fankhauser's suggested a range between 1.1-1.5 % of GWP. Using the estimates compiled by the three authors and assuming that damage cost equals 1 % of GWP and applying a consistent discount rate, Brown and Pearce (1993) reported global warming damage of the order of US$7-18 tC^{-1}. If zero discount rate was used, they reported that the upper range could be as high as RM100 (US$40 tC^{-1}).

4 If RIL is to be done at all, it has to be paid for: at the Innoprise level by paying the workers properly; at the NEP level by paying Innoprise the actual costs; at the world level by working out appropriate transfer mechanisms. For example, there is a need to compensate timber feller and bulldozer/hookman crew involved in RIL because of the changes in responsibilities. This study recommends that the timber feller's wage be increased from RM1.30 m^{-3} to RM2.20 m^{-3} for the longer time required to carry out directional felling. Similarly, the bulldozer operator and

hookman's wage should be increased from RM2 m^{-3} to RM3 m^{-3} to compensate for the longer working hours.

Based on the above findings, the following are recommended:

1 Institute cost reduction measures for RIL. Firstly, the cost of stock mapping alone amounts to RM143 ha^{-1}, and is the most expensive activity among the additional elements required in RIL. Stock mapping cost may be reduced by confining the field work to loggable areas only. Secondly, some cost-saving can be realised after removing transaction costs (brokerage commission), consultancy and training expenses. However, these cost-reduction measures have little impact on the overall economics of RIL. There are other 'hidden' costs or 'hard to quantify' costs such as the shut–down of logging operation during wet weather.

2 The significance and economic implication of the displaced logging problem warrants a review of the RIL harvesting guidelines in two aspects, i.e.:

(i) those that would lead to a reduced proportion of the area of a forest management unit actually being logged;

(ii) those that involve much more careful harvesting of timber from the area actually logged (these guidelines have a smaller influence via the lower timber yield per area of RIL)

On (i) above, the planning and construction of a timber extraction route network constituted an important part of the logging operation. A well-planned road system not only minimized soil erosion, but also determined the layout and alignment of secondary roads as well as skid trails. In turn, this determined the efficiency of timber production. The location of roads was, therefore, crucial when a logging operation was carried out in hilly terrain such as that in the study area and the remaining areas of the Sabah Foundation forest concession.

There were three possibilities for roads to be located in a given area namely, on ridge top, mid–slope or lower slope. RIL required roads to be located on ridge top because up-hill skidding was encouraged in order to disperse runoff water into the vegetation whereas downhill skidding tends to concentrate it at the log landing (Dykstra and Heinrich, 1992). It might also be cheaper to construct (not necessarily on hilly and broken terrain because of more bridges being needed) and cause less soil disturbance.

However, restricting roads only to ridge top unnecessarily restricts the area available for extraction because there would be enclaves along a slope that could still be harvested which would seem too steep from the ridge top. The requirement to have roads located along the ridge top at all times is specified in the RIL guidelines, which might have resulted in a large area left unlogged. However, building roads on mid-slope may cause greater soil disturbance because of extensive side-cutting along hill slopes. In addition, total road density might be higher (longer roads having to be cut along both sides of the hill instead of one main road along the ridge).

In relation to the extraction routes, the RIL guidelines prohibited side-cutting of hill slopes greater than 25° in order to minimise adverse effects of soil erosion. By default, this guideline encouraged roads and skid trails to be located on higher ground (ridge top). This effectively restricted the accessibility to a larger tract of forest with hilly terrain. Relaxing the hill slope specification could increase the area loggable by RIL. The net environmental impact of relaxing the slope criteria, however, might be adverse.

3 RIL makes it infeasible to harvest some forest areas that would have otherwise been logged. The removal of this commercial forest from production has yielded some environmental gains: however, the financial and economic implications for the timber producer and country could be significant. There may be a case to use alternative logging technologies such as helicopter logging to harvest these areas which under RIL guidelines are unloggable by ground-based logging system.

Cable harvesting systems are another option to harvest trees in environmentally sensitive areas such as on steep zones. Presently, the Sabah Forestry Department through the Malaysian-German Sustainable Forest Management Project is testing the feasibility of a skyline system in logged forests. The estimated cost of skyline operation in Sabah forest conditions was RM42 m^{-3}, about twice the tractor skidding costs (Benneckendorf, 1993)). However, the higher costs for skyline may be offset by the lesser extent of damage to the timber stock (total damage to trees ranges between 24–27 %), minimal loss of forest area to roads and skid trails (98 % of the logging area remained intact), and lower machine maintenance costs. The implications of using alternative systems is that they would incur different economic costs and benefits, some of which have been quantified in this thesis.

4 Timber that is produced from RIL could be sold to niche markets that attract a price premium to offset costs (e.g. Dubois *et. al.*, 1995). Although there is some evidence that there is willingness to pay for a higher price of certified products in

certain importing markets, there is still considerable controversy about the size of the niche markets, the willingness-to-pay, and the costs of certifications. A recent study conducted for the European market revealed that total niche market share for certified products was well below 3 % out of a total consumption of about 56.1 million m^3 of sawnwood and wood–based panels (Rametsteiner *et. al.*, 1998). According to the Rametstenier *et. al.* survey, the volume of certified timber which will be traded in Europe in 1998 is estimated to be only between 2–15 million m^3; the vast majority of forest owners were either not willing to spend anything, or up to a maximum of 2 % of their timber income; the majority of consumers (90%) of the companies surveyed in Germany, Finland, Britain thought that the majority of their customers would not be willing to pay a higher price for certified products.

The consensus among tropical timber producers is that timber certification will increase production costs. Baharuddin (1995) estimated that the costs of certification assessments would be between US$0.30–1.00 ha^{-1} yr^{-1} in tropical countries using local expertise. The costs of doing a chain–of–custody were estimated to be up to one percent of the timber prices (Baharuddin and Simula, 1994). Such increase in costs, however, does not necessarily correlate to higher prices for final tropical timber products (Vincent, 1995). This imposes a further financial burden on the concessionaire in shifting to sustainable forest management practices. The implication is that RIL will be less likely to be favoured over conventional logging practices.

5 The joint implementation (JI) or the clean develop mechanism (CDM) schemes under the auspices of the United Nations Framework Convention on Climate Change offer the greatest potential for international co-operation in sharing the cost burden of sustainable forest management goals. Other schemes that essentially provide the mechanism for trade in forest services include debt–for–nature swaps, carbon offset, internationally tradable carbon dioxide permits and tradable development rights. It is unfortunate that the carbon sequestration benefit associated with improved forest management represents a high-cost way to achieve this transition based on the finding of this study. Unless non-market values are made more cashable, RIL is unlikely to be the most profitable option from the private point of view.

6 If international funding is not forthcoming, the only recourse to address the additional cost of RIL would be to consider partial RIL (log the same area as CL) as a more economically acceptable alternative. The justification for taking this course of action is underlined by the dominant use theory advocated by Bowes and Krutilla (1989) for temperate forest. The theory predicts that multiple-use management of

individual stands is less efficient than dominant-use management: that is, some stands should be managed more intensively for timber production, while others are managed more intensively for production of non-timber values (Vincent and Binkley, 1993). Dominant use is consistent with the tradition in many tropical countries of separating a permanent forest reserve according to commercial forest, protection forest and amenity forest (Vincent, 1998). In Sabah, commercial forest is one of the seven classes of forest under the permanent forest estates.

By using partial RIL, some elements within the RIL harvesting guidelines would have to be relaxed. In particular, it should not be made compulsory that roads always be located on the ridge top as this has a significant effect on the exclusion of area for logging. It is also recommended that the slope restriction with regard to the location of skid trails and roads be relaxed in order to access enclaves. Apart from these, compliance with the other guidelines is essential to minimise on-site and off-site disturbances.

In conclusion, this study has made some progress in valuing empirically six forest values that can be derived from a tropical forest. It is not the intention to leave the impression of comfortable certainty with regard to the forest resource and its values. The range of uncertainties, biological, ecological and economic, that surround forests is still not well understood. Given the complexity, economic assessments and projections will necessarily be somewhat speculative. Therefore, results of the economic analysis should not be seen as fine-tuned numbers, but more to indicate orders of magnitude which enable the identification of the key sensitive parameters. This should not be construed as a criticism of all that has been done, but an assertion of the need to recognize its practical limitations.

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Appendix 2.1 The timber royalty system of Sabah

Sabah uses a formula approach to setting royalty charges on logs. The levels of the charges are based on a relationship with prices, costs, distance and stand conditions or terrain. The charges are reviewed quarterly. The royalty formulae for logs are as follows;

1. For FOB (free on board ship, port of loading) price of timber less than RM220 m^{-3}

   $R = 0.6 \times (FOB-LC \text{ at RM})$

2. For FOB price of timber more than RM220 m^{-3}

   $R = 0.7 \times (FOB-LC \text{ at RM63})$

Where FOB = FOB log price in RM m^{-3}
R = Royalty rate at RM m^{-3}
LC = Logging costs in RM m^{-3}

The formulae are applied as follows;

- Timber species or species groups have been classified into nine royalty classes of comparable FOB prices from A to H plus OT (other timbers)
- Average FOB price of each class in the previous month is taken as the FOB value for that class in computing the royalty rate of the class for the current month
- The royalty rate resulting from the computation is then finalized between officials from the timber trader/operator and the relevant government departments to arrive at the effective rate for each month

Class*	Timber Species Groups (Common Names)	Royalty Rate (RM m^{-3})
A	Belian/Merbau	350-500
B	Belian	260-380
C	Seraya (Red/White/Yellow) Nyato/Oba Suluk/Selangan Batu/Perupok Kapor/Keruing/Pengiran/Kembang/ Tengkawang	200-300
E	Kembang semangkok/Jelutong/Bawang Hutan	100-140
F	Maga/Sendok/Binuang/Sepetir/Putat Paya/ Kedondong/Pauh Kijang/Karai	100-120
G	Resak/Rengas/Talisai/Terentang/Takalis/ Bawang/Obah/Ranggu/Bintagor/Perapat/ Darah/Bangkal/Mempening/Pulai/Keranji/ Geronggang/Terap/Cempaka/Medang	90-100
H	Menggaris/Durian/Simpoh/Bayur/Impas/ Teluto/Limau/Gaharu/Kandis	70-80
I	Ranggu	60-70
J	Other timbers	40-50

* The classification of timber into the nine species groups is based on their utilisation properties. Timber of classes A and B is of high density and is durable. Class C timber is light to medium density. Class E, F and G timber is light to medium density and comprises some fruit trees species. Class H timber is medium to high density and the species only occurs in small quantities in a given area. Class J is timber of lesser-known species that does not fall into any of the previous classes.

Appendix 2.2 Sabah log grading rules (Source: Sabah Forestry Department, 1980)

The Sabah Log Grading Rules (SLGR) were first published in 1965 by the Sabah Forestry Department. The metric version was published in 1980. The SLGR (1980) provides for five classes of log grades namely *Prime Grade*, *Second* Quality, *Fair Average Quality* (FAQ), *Superior Sawmill Grade* (SSQ), and *Sawmill Grade* (SQ). Four other log grade classes that have been used extensively in Sabah are yet to be included in the SLGR (1980). There are *Millable Quality* (MQ), *Low Millable Quality* (MQL), *Low Grade* (LG) and *Small* (Chaiyapechara, 1988).

Definition of log grades

I PRIME

Logs shall be 70 % cylindrical and fresh cut with well cross-cut ends. They shall be free from attack by marine borer, spiral hole (*lobang pusing*) and rot, and free from shakes. Logs less than 4.2 m in length and 78 cm in diameter shall be free of all visible natural defects. Logs 4.2 m in length and over, and of any diameter, shall be allowed one unit for knot, shot-hole, split, defective heart or bend but not more than two kinds of defects will be allowed in any log. Twisted logs will not be accepted. Trimmed buttresses shall be admitted. Species shall be as stated (all species in Appendix 2.1 except some species in Group C i.e. Kapor and Keruing).

II SECOND QUALITY

Logs shall be 70 % cylindrical, with well cross-cut ends, but not necessarily fresh cut. They shall be free from marine borer and spiral hole attack and from shakes. Logs less than 3.6 m in length and 69 cm in diameter shall be free from all visible natural defects. Logs 3.6 m in length and over, of any diameter, will be allowed two units of knot, shot-hole, split or heart but not more than two kinds of defect will be allowed in any log. Twisted logs will not be accepted. Trimmed buttresses shall be admitted. Species shall be as stated (all species in Appendix 2.1 except some species in Group C i.e. Kapor and Keruing).

III FAIR AVERAGE QUALITY (FAQ)

Logs shall not necessarily be fresh-cut but they shall be free from marine borer and spiral hole attack. Logs will be allowed three units for knot and shot-hole, and two units for split, heart or bend but not more than two kinds of defect will be allowed in any log. Twisted logs will not be accepted. Trimmed buttresses shall be admitted. Species shall be as stated (all species in Appendix 2.1 except some species in Group C i.e. Kapor and Keruing).

IV SUPERIOR SAWMILL QUALITY (SSQ)

Logs shall not necessarily be fresh-cut but they shall be free from marine borer and spiral hole attack. Logs will be allowed three units for knot or worm hole and two units for bend and split. Heart defects, including piped heart will be accepted at both end of the log up to 10 % of the diameter of the log, measured at the smaller end, under bark. Not more than three kinds of defect will be admitted in any log. Twisted logs will be accepted. Trimmed buttresses shall be admitted. Species shall be as stated (all species in Appendix 2.1 except some species in Group C i.e. Kapor and Keruing).

V SAWMILL QUALITY (SQ)

Marine borer and spiral hole attack will be accepted provided that, together with the defects specified in the next paragraph, not less than 60 % of the volume of the log shall be free of all defects. Defects will be allowed in excess of the number permitted in Fair Average Quality except for bend and split, provided that not less than 60 % of the volume of the logs shall be free of all defects. Twisted logs will be accepted. Trimmed buttresses shall be admitted. Species shall be as stated (all species in Appendix 2.1).

V MILLABLE QUALITY (MQ)

The MQ grade shall admit all defects in excess of that specified in the SQ grade, and not less than 50-60 % of the logs shall be free of all defects.

VI LOW MILLABLE QUALITY (MQL)

The MQL grade shall admit all defects in excess of that specified in the MQ grade, and not less than 35-50 % of the logs shall be free of all defects.

VII LOW GRADE

The Low Grade admits more defects than MQL.

VIII SMALL

This grade admits logs that are less than 59 cm DBH. However, the main determinant for admitting logs into this class is the log price rather than defects i.e. logs classified under SMALL may include either defective or non-defective logs.

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Note: In 1975, the South East Asia Lumber Producers Association (SEALPA) Technical and Marketing Committees formulated the SEALPA Log Grading Rules with the intention to standardised the log grading rules among the member countries. The rules were intended for use in grading logs other than teak species, produced by Malaysia, Indonesia, Papua New Guinea and the Philippines. The Rules were formally adopted by the SEALPA Council 9th Meeting in Sanur, on October 12, 1978. In developing the Rules, the Committee recognised the advancement in wood technology and expanded the grading rules to cover veneer and chipwood production. The Committee also recognised that the resource base is now located mainly in hilly and rugged terrain where the quality of trees is lower due to both natural and technical defects (ICSB, 1987).

Sabah has not adopted the SEALPA Log Grading Rules and still uses the Sabah Log Grading Rules (1980) as the basis of grading logs.

Appendix 3.1 Volume Table Equation

There are 15 volume tables applicable to the mixed dipterocarp forests of Sabah. The 15 volume tables give gross volume (inside bark) for individual species or species groups up to first branching or at 4.7 cm top diameter whichever occurs first. The diameter is measured at 1.3 m above stump height (FO:DP/MAL/85/004).

The Forestry Department has identified a list of 253 species for inventory purposes. Each species has an individual code number of six digits of which the first two relate to merchantability, the other four to species identification. The 253 species are grouped into eleven groups based on their utilization characteristics. Utilization code 1 to 8 refers to species of established commercial importance mainly exported as round logs or processed. Group 9, 10 and 11 comprise species in accordance with their utility (i.e. veneer and plywood, construction and general utilities, and other uses)

Species group	Volume equation
1	$V = 6.711 + 0.3628\ D^2H/100$
2	$V = 11.190 + 0.3427\ D^2H/100$
3	$V = 1.922 + 0.3486\ D^2H/100 + 0.000006589\ (D^2H/100)^2$
4	$V = 2.048 + 0.3429\ D^2H/100$
5	$V = 7.266 + 0.5974\ D^2H$ for $D^2H<425$ $V = 38.360 + 0.5238\ D^2H$ for $D^2H>425$
6	$V = 7.153 + 0.3172\ D^2H/100 + 0.000009377\ (D^2H/100)^2$
7	$V = 5.070 + 0.3440\ D^2H/100$
8	$V = 2.544 + 0.3803\ D^2H/100$
9	$V = 4.015 + 0.3715\ D^2H/100$
10	$V = 4.015 + 0.3715\ D^2H/100$
11	$V = 5.188 + 0.3253\ D^2H/100$
12	$V = 4.574 + 0.4040\ D^2H/100$
13	$V = 3.720 + 0.3659\ D^2H/100$
14	$V = 6.644 + 0.2845\ D^2H/100 + 0.00001686\ (D^2H/100)^2$
15	$V = 3.004 + 0.3523\ D^2H/100$

Source: Volume table group no. 1-4, 6-15 from Forestal International Ltd (Project no. F644/72)
Volume table group no. 5 from FAO: DP/MAL/72/009

Appendix 4.1 Summary of projected timber composition and volumes for RIL and CL units (Mean 4 RIL and 4 CL units)

Logging Unit	RIL																			
Year	0										20									
	10-20		20-40		40-60		>60		All		10-20		20-40		40-60		>60		All	
	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha
DIPTEROCARP																				
Red Seraya	9 09	0 60	6 21	4 20	1 42	3 80	4 21	43 49	20 93	52 08	34 98	2 32	6 23	4 91	2 03	5 01	3 73	43 43	46 91	55 67
White Seraya	21 52	1 42	10 20	6 53	4 88	10 94	3 77	43.74	40 37	62 63	4 43	0 29	17 33	9 88	6 02	14 46	4 02	45 29	31 69	69 92
Melapi	0 88	0 06	0 00	0 00	0 00	0 00	0 00	0 00	0 88	0 06	0 00	0 00	1 52	0 44	0 46	0 00	0 00	0 00	1 52	0 44
Yellow Seraya	3 39	0 23	0 24	0 12	0 00	0 00	1 09	9 93	4 71	10 28	1 77	0 12	0 66	0 67	1 41	0 00	0 96	9 23	3 39	10 02
Kapur	0 57	0 04	0 57	0 51	0 57	2 05	0 00	0 00	1 70	2 60	23 28	1 54	0 91	0 77	0 00	0 00	0 31	1 43	24 50	3 74
Keruing	0 31	0 02	0 63	0 26	0 00	0 00	0 00	0 00	0 94	0 28	0 29	0 02	0 48	0 32	0 00	0 00	0 00	1 18	0 76	1 52
Selangan	0 00	0 00	0 00	0 00	0 00	0 00	0 41	2 46	0 41	2 46	0 00	0 00	0 00	0 00	0 00	0 00	0 34	1 04	0 34	1 04
Selangan Batu	2 14	0 14	2 90	1 80	0 31	0 86	0 20	1 25	5 55	4 05	3 34	0 22	1 96	1 19	0 26	1 42	0 17	1 16	6 18	3 99
Resak	0 39	0 03	7 21	0 41	1 88	0 00	3 45	0 00	1 35	0 44	0 30	0 02	7 13	0 67	2 58	0 00	2 84	0 00	1 05	0 69
Sub-Total	38 28	2 53	21 69	13 84	7 18	17 64	9 68	100 86	76 83	134 86	68 38	4 45	29 82	18 86	8 62	20 89	9 54	102 75	116 35	147 02
NON-DIPTEROCARP																				
Merbau/Sepatir	1 38	0 09	0 24	0 28	0 00	0 00	0 25	2 93	1 87	3 29	0 82	0 06	0 22	0 04	0 19	0 20	0 20	2 34	1 43	2 64
Kembang	3 59	0 24	0 00	0 00	0 57	1 30	0 00	0 00	4 16	1 54	2 68	0 18	0 18	0 04	0 48	1 43	0 00	0 00	3 34	1 64
Nyatoh	1 58	0 11	0 00	0 11	0 00	0 00	0 00	0 00	1 58	0 21	0 88	0 06	0 33	0 12	0 00	0 00	0 00	0 00	1 21	0 18
Pisang-pisang	11 00	0 73	1 12	0 28	0 00	0 00	0 00	0 00	12 12	1 01	5 16	0 34	3 63	1 48	0 00	0 00	0 00	0 00	8 79	1 83
Mempening	4 60	0 30	3 58	1 86	0 79	0 88	0 00	0 00	8 97	3 04	0 63	0 04	4 74	2 76	1 39	2 06	0 00	0 00	6 77	4 86
Medang	16 14	1 06	6 60	2 91	1 18	1 41	0 25	0 98	24 17	6 36	9 41	0 62	8 39	4 02	1 92	2 82	0 20	0 89	19 92	8 34
Other Timbers	34 53	2 28	17 85	9 62	3 72	6 87	1 73	8 72	57 83	27 48	108 89	7 19	20 25	11 86	5 32	8 54	2 07	10 72	136 52	38 30
Sub-Total	72 81	4 81	29 38	15 04	6 26	10 46	2 24	12 62	110 69	42 93	128	8 49	37 74	20 31	9 30	15 04	2 47	13 95	177 97	57 79
PIONEERS	1 80	0 04	0 00	0 00	0 31	0 84	0 00	0 00	2 12	0 88	8 54	0 56	0 23	0 08	0 00	0 00	0 12	0 57	8 89	1 21
NON-COMM TIMBERS	129 78	8 64	43 65	18 49	5 87	9 48	0 99	5 72	180 28	42 32	127 58	8 42	49 96	27 17	8 20	12 57	0 83	4 74	187	52 90
Total	243	16 02	95	47 37	20	38 41	13	119 20	370	220 99	333	21 99	118	66 42	26	48 50	13	122 01	490	258 92

Logging Unit	CL																			
Year	0										20									
DIPTEROCARP	10-20		20-40		40-60		>60		All		10-20		20-40		40-60		>60		All	
	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha	T/ha	m^3/ha
Red Seraya	5 10	0 34	4 88	3 24	3 45	7 16	1 76	20 48	15 18	31 21	29 56	1 95	5 19	3 63	4 14	11 73	1 57	19 69	40 46	37 00
White Seraya	13 77	0 91	11 94	6 82	5 27	12 45	1 28	9 00	32 26	29 18	3 83	0 25	13 36	9 09	6 12	13 52	2 27	17 16	25 57	40 02
Melapi	0 49	0 03	0 00	0 00	0 26	0 55	0 00	0 00	0 75	0 59	0 23	0 02	0 20	0 12	0 22	0 75	0 00	0 00	0 65	0 89
Yellow Seraya	0 50	0 03	1 25	0 74	1 25	2 84	0 34	5 72	3 34	9 33	0 19	0 01	0 91	0 75	1 07	2 85	0 40	5 28	2 58	8 89
Kapur	1 50	0 10	1 30	0 70	0 52	1 33	0 32	2 66	3 64	4 79	17 84	1 18	1 46	1 14	0 21	0 63	0 41	3 12	19 91	6 06
Keruing	1 28	0 09	1 28	0 94	0 76	2 46	0 66	5 80	3 99	9 28	0 88	0 06	0 77	0 45	0 83	2 35	0 69	6 41	3 16	9 28
Selangan	0 00	0 00	0 52	0 31	0 00	0 00	0 00	0 00	0 52	0 31	0 00	0 00	0 40	0 42	0 00	0 00	0 00	0 00	0 40	0 42
Selangan Batu	0 76	0 05	0 00	0 00	0 00	0 00	0 51	4 47	1 27	4 52	2 37	0 16	0 18	0 06	0 00	0 00	0 41	3 73	2 96	3 94
Resak	0 00	0 00	0 75	0 71	0 00	0 00	0 00	0 00	0 75	0 71	0 00	0 00	0 21	0 25	0 39	0 53	0 00	0 00	0 60	0 77
Sub-Total	23 40	1 55	21 92	13 45	11 51	26 79	4 87	48 13	61 69	89 90	54 90	3 62	22 67	15 91	12 97	32 36	5 75	55 39	96 29	107 27
NON-DIPTEROCARP																				
Merbau/Sepatir	0 50	0 03	0 47	0 15	0 26	0 24	0 17	1 19	1 40	1 61	0 36	0 03	0 36	0 17	0 22	0 28	0 14	1 11	1 08	1 58
Kembang	2 92	0 19	0 00	0 00	0 00	0 00	0 00	0 00	2 92	0 19	2 28	0 15	0 21	0 05	0 00	0 00	0 00	0 00	2 49	0 20
Nyatoh	1 02	0 07	0 48	0 32	0 00	0 00	0 00	0 00	1 50	0 39	0 47	0 03	0 59	0 49	0 00	0 00	0 00	0 00	1 06	0 52
Pisang-pisang	12 25	0 81	3 73	1 24	0 50	0 64	0 00	0 00	16 47	2 69	6 33	0 42	5 52	2 84	0 40	0 68	0 00	0 00	12 25	3 94
Mempening	2 43	0 16	2 28	1 22	0 24	0 35	0 00	0 00	4 94	1 73	0 37	0 03	2 80	1 77	0 59	0 96	0 00	0 00	3 76	2 75
Medang	9 05	0 60	5 44	2 42	0 73	0 77	0 17	0 72	15 39	4 50	4 86	0 32	6 37	3 45	1 18	1 71	0 14	0 67	12 55	6 15
Other Timbers	19 20	1 27	9 41	5 06	4 23	7 24	1 15	6 49	33 98	20 05	112 10	7 40	11 91	6 69	4 40	8 00	1 36	7 53	129 76	29 61
Sub-Total	47 35	3 12	21 81	10 40	5 96	9 23	1 49	8 40	76 61	31 15	126 76	8 37	27 75	15 45	6 78	11 62	1 65	9 31	162 94	44 74
PIONEERS	2 61	0 17	0 24	0 12	0 00	0 00	0 00	0 00	2 85	0 29	11 75	0 78	0 17	0 08	0 04	0 05	0 00	0 00	11 96	0 91
NON-COMM TIMBERS	68 14	4 50	24 83	10 40	3 33	5 21	0 60	0 63	96 89	20 74	88 95	5 87	31 08	15 79	5 64	7 90	0 13	0 53	125 79	30 10
Total	141	9 34	69	34 37	21	41 23	7	57 15	238	142 08	282	18 63	82	47 23	25	51 93	8	65 24	397	183 01

Note Cell values are mean values of four logging units and therefore do not add-up to sub-totals and totals.

Appendix 4.1

Logging Unit	RIL																			
Year	40										60									
	10-20		20-40		40-60		>60		All		10-20		20-40		40-60		>60		All	
	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha
DIPTEROCARP																				
Red Seraya	50.63	3.34	12.65	7.13	3.20	7.35	2.14	42.98	68.62	60.79	56.75	3.75	24.78	15.69	3.21	8.97	1.92	41.35	86.66	0.00
White Seraya	0.00	0.00	13.33	11.90	6.79	16.33	3.01	50.51	23.13	78.73	0.00	0.00	3.15	3.92	10.73	22.89	3.58	58.01	17.46	69.74
Melapi	0.00	0.00	0.66	0.66	0.00	0.25	0.00	0.00	0.66	0.90	0.00	0.00	0.34	0.51	0.24	0.86	0.00	0.00	0.58	84.82
Yellow Seraya	0.00	0.00	2.29	1.59	0.17	0.00	0.51	8.27	2.98	9.86	0.00	0.00	1.53	1.84	0.40	0.20	0.39	6.74	2.31	1.37
Kapur	40.06	2.65	3.81	1.12	0.36	0.55	0.16	1.42	44.39	5.73	46.70	2.20	14.66	5.66	0.30	0.65	0.13	1.40	61.78	8.77
Keruing	0.00	0.00	0.61	0.54	0.00	0.00	0.12	0.00	0.73	0.54	0.00	0.88	0.21	0.19	0.30	0.56	0.00	0.00	0.51	9.91
Selangan	0.00	0.00	0.00	0.00	0.00	0.00	0.07	2.02	0.07	2.02	0.00	0.00	0.00	0.00	0.00	0.00	0.16	1.77	0.16	1.63
Selangan Batu	3.42	0.23	1.88	1.10	0.56	0.86	0.18	1.54	6.04	3.72	3.90	0.19	1.85	1.25	0.46	0.86	0.15	1.41	6.35	1.77
Resak	0.00	0.00	7.76	0.43	3.68	0.41	0.00	0.00	0.83	0.84	0.00	0.07	11.26	0.15	4.12	0.92	1.96	0.00	0.66	3.71
Sub-Total	94	6.10	35.70	24.45	11.45	25.72	6.19	106.73	147.45	163.12	107	6.96	46.69	29.18	16.11	35.90	6.33	110.67	176.47	182.84
NON-DIPTEROCARP																				
Merbau/Sepatir	0.00	0.00	0.79	0.24	0.16	0.22	0.10	1.87	1.04	2.33	0.00	0.00	0.59	0.31	0.13	0.24	0.08	1.52	0.80	2.06
Kembang	0.27	0.02	2.17	0.68	0.39	1.40	0.00	0.00	2.83	2.09	0.00	0.00	1.83	1.27	0.14	0.16	0.13	0.86	2.10	2.29
Nyatoh	0.53	0.04	0.37	0.21	0.00	0.00	0.00	0.00	0.90	0.25	0.08	0.01	0.52	0.32	0.00	0.00	0.00	0.00	0.59	0.33
Pisang-pisang	1.91	0.13	4.39	2.55	0.16	0.15	0.00	0.00	6.46	2.83	0.34	0.02	3.90	2.91	0.59	0.65	0.00	0.00	4.83	3.58
Mempening	0.00	0.00	2.69	2.19	2.74	4.14	0.00	0.00	5.43	6.33	0.00	0.00	0.70	0.82	3.62	6.30	0.00	0.00	4.31	7.12
Medang	2.65	0.18	10.35	4.87	3.12	5.22	0.11	0.84	16.22	11.10	0.00	0.00	8.59	5.60	3.99	7.63	0.09	0.75	12.68	13.97
Other Timbers	155.25	10.24	22.10	12.84	8.49	14.82	1.21	11.54	187.05	49.44	190.21	12.55	15.31	11.10	11.35	19.97	1.31	12.93	218.17	56.55
Sub-Total	161	10.59	42.85	23.58	15.05	25.94	1.42	14.25	219.94	74.37	191	12.58	31.44	22.33	19.80	34.93	1.62	16.06	243.48	85.90
PIONEERS	10.00	0.66	0.00	0.00	0.08	0.07	0.06	0.63	10.13	1.36	6.56	0.44	0.04	0.01	0.06	0.17	0.05	0.64	6.71	1.24
NON-COMM TIMBERS	127.18	8.40	41.67	29.40	15.79	21.41	4.76	4.19	189.40	63.39	131.99	8.71	35.31	26.58	25.04	33.81	4.58	3.59	196.91	72.69
Total	392	25.86	120	77.43	42	73.15	12	125.80	567	302.24	437	28.81	113	78.09	61	104.81	13	130.96	624	342.66

Logging Unit	CL																			
Year	40										60									
DIPTEROCARP	10-20		20-40		40-60		>60		All		10-20		20-40		40-60		>60		All	
	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha	T/ha	m³/ha
Red Seraya	44.77	2.96	11.60	6.68	3.46	9.87	2.28	23.74	62.10	43.24	50.50	3.33	24.27	15.68	2.58	6.64	2.79	27.64	80.15	53.28
White Seraya	0.00	0.00	8.67	7.65	8.13	18.07	3.21	25.86	20.01	51.58	0.00	0.00	1.71	2.18	9.00	21.57	4.53	37.01	15.24	60.76
Melapi	0.00	0.00	0.39	0.29	0.00	0.00	0.12	0.57	0.50	0.87	0.00	0.00	0.21	0.19	0.13	0.23	0.09	0.63	0.43	1.04
Yellow Seraya	0.00	0.00	0.39	0.35	0.91	2.13	0.58	5.64	1.89	8.12	0.00	0.00	0.12	0.13	0.63	1.42	0.66	5.67	1.40	7.22
Kapur	29.47	1.41	4.51	1.52	0.67	0.86	0.46	3.54	35.10	7.35	36.88	2.43	12.26	5.25	0.67	1.36	0.38	3.35	50.18	12.40
Keruing	0.00	0.54	1.39	0.88	0.51	1.63	0.68	6.70	2.58	9.95	0.00	0.00	0.88	0.65	0.61	1.81	0.67	7.02	2.15	9.48
Selangan	0.00	0.00	0.15	0.21	0.18	0.32	0.00	0.00	0.32	0.53	0.00	0.00	0.00	0.00	0.25	0.56	0.00	0.00	0.25	0.56
Selangan Batu	3.13	0.16	0.28	0.12	0.00	0.00	0.34	3.14	3.74	3.42	3.99	0.26	0.33	0.17	0.00	0.00	0.28	2.71	4.60	3.13
Resak	0.00	0.05	0.00	0.00	0.48	0.93	0.00	0.00	0.48	0.98	0.00	0.00	0.00	0.00	0.39	1.11	0.00	0.00	0.39	1.11
Sub-Total	77.36	5.05	27.36	17.70	14.34	34.04	7.66	69.19	126.72	126.04	91.37	6.01	39.77	24.23	14.25	34.69	9.41	84.03	154.79	148.98
NON-DIPTEROCARP																				
Merbau/Sepatir	0.00	0.00	0.55	0.26	0.18	0.30	0.12	1.03	0.84	1.59	0.00	0.00	0.43	0.29	0.14	0.29	0.10	0.93	0.66	1.50
Kembang	0.00	0.00	2.10	0.70	0.00	0.00	0.00	0.00	2.10	0.70	0.00	0.00	1.56	1.28	0.11	0.13	0.00	0.00	1.66	1.40
Nyatoh	0.20	0.01	0.45	0.31	0.16	0.24	0.00	0.00	0.81	0.55	0.17	0.01	0.22	0.13	0.25	0.46	0.00	0.00	0.64	0.60
Pisang-pisang	2.92	0.20	5.44	3.69	0.96	1.28	0.00	0.00	9.31	5.17	0.40	0.02	4.78	3.47	2.13	2.70	0.00	0.00	7.30	6.18
Mempening	0.00	0.00	1.57	1.33	1.40	2.14	0.00	0.00	2.97	3.47	0.00	0.01	0.30	0.32	2.01	3.46	0.00	0.00	2.31	3.79
Medang	1.20	0.08	6.99	4.26	1.89	3.24	0.12	0.59	10.20	8.17	0.00	0.00	4.49	3.04	3.51	6.22	0.09	0.52	8.09	9.78
Other Timbers	168.67	11.13	12.16	6.66	6.38	11.54	1.35	8.41	188.56	37.74	196.83	12.99	10.65	6.03	7.38	14.32	1.39	8.63	216.25	41.96
Sub-Total	172.98	11.42	29.25	17.20	10.97	18.73	1.58	10.04	214.78	57.39	197.39	13.03	22.41	14.55	15.52	27.57	1.59	10.08	236.91	65.22
PIONEERS	14.65	0.97	0.00	0.00	0.05	0.10	0.00	0.00	14.70	1.07	8.67	0.57	0.25	0.05	0.00	0.06	0.02	0.03	8.94	0.72
NON-COMM TIMBERS	108.63	7.17	30.36	17.89	8.00	13.57	1.40	0.44	148.38	39.06	125.33	8.27	25.67	15.56	15.33	20.81	0.18	0.70	166.51	45.33
Total	375	24.66	87	52.79	33	66.43	11	79.67	505	223.56	423	27.90	88	54.40	45	83.13	11	94.64	567	260.25

Appendix 4.2 Timber stock valuation in units logged with conventional logging (CL).

Assumptions:

1)	Proportion of trees 40-60 cm DBH harvested	7	% (based on this study)
2)	Proportion of trees 40-60 cm DBH dead after logging	4	% (based on actual data 8-12 months after logging only for crown, stem and bark damage)
3)	Proportion of trees >60 cm DBH dead after logging	2	% (Based on actual data 8-12 months after logging only for crown, stem and bark damage)
4)	Annual real price rise for all timber grades	2	% (Based on ITTO report (1993))
5)	Proportion of utilizable wood	70	% (Bhargava and Kugan, 1988)

		TIMBER GRADES PROPORTION (%)						TIMBER PRICE BY GRADES (RM/m3)					
		FAQ	SSQ	SQ	MQ	SM/SSM	MQL	FAQ	SSQ	SQ	MQ	SM/SSM	MQL
COMMERCIAL	*DIPTEROCARP*												
	Red Seraya	4	8	50	20	9	9	286	276	234	197	157	147
	White Seraya	13	14	45	14	8	6	286	276	234	197	157	147
	Melapi	14	12	44	11	16	3	213	203	186	165	157	147
	Yellow Seraya	9	10	43	19	8	11	213	203	186	165	157	147
	Kapur	0	0	72	9	14	5	0	0	177	160	157	147
	Keruing	0	0	69	9	20	2	0	0	178	160	157	147
	Selangan	0	0	68	10	13	9	0	0	176	159	157	139
	Selangan Batu	0	0	66	15	9	10	0	0	176	139	157	147
	Resak	3	2	53	10	22	10	164	164	164	164	157	147
	NON-DIPTEROCARP												
	Merbau/Sepatir	0	0	55	30	0	15	314	314	314	314	157	147
	Kembang	0	0	68	32	0	0	164	164	164	164	157	147
	Nyatoh	0	7	39	20	17	17	213	203	186	165	157	147
	Pisang-pisang	0	0	51	49	0	0	164	164	164	164	157	147
	Mempening	0	0	50	50	0	0	164	164	164	164	157	147
	Medang	0	0	75	25	0	0	164	164	164	164	157	147
	Other Timbers	3	2	53	10	22	10	164	164	164	164	157	147
	PIONEERS	0	0	49	15	22	14	164	164	164	164	157	147
NON-COMMERCIAL	Timbers species	0	0	0	0	0	0	0	0	0	0	0	0

SPECIES	GROSS YIELD (m3/ha)			NET YIELD (m3/ha)			TIMBER YIELD BY GRADES (m3/ha)						TIMBER VALUE BY GRADES (RM/ha)						TOTAL	MEAN
	40<60	>60	> 40	40<60	>60	> 40	FAQ	SSQ	SQ	MQ	SM/SSM	MQL	FAQ	SSQ	SQ	MQ	SM/SSM	MQL	RM/ha	RM/m3
AT YEAR	**0**																			
DIPTEROCARP																				
Red Seraya	7.16	20.48	27.63	0.34	14.05	14.38	0.575	1.151	7.192	2.877	1.295	1.295	164.55	317.59	1682.87	566.71	203.24	190.29	3,125	
White Seraya	12.45	9.00	21.45	0.59	6.17	6.76	0.879	0.946	3.041	0.946	0.541	0.405	251.27	261.13	711.63	186.39	84.88	59.61	1,555	
Melapi	0.55	0.00	0.55	0.03	0.00	0.03	0.004	0.003	0.011	0.003	0.004	0.001	0.78	0.63	2.13	0.47	0.65	0.11	5	
Yellow Seraya	2.84	5.72	8.56	0.13	3.93	4.06	0.365	0.406	1.745	0.771	0.325	0.446	77.80	82.39	324.60	127.23	50.97	65.63	729	
Kapur	1.33	2.66	3.99	0.06	1.82	1.89	0.000	0.000	1.359	0.170	0.264	0.094	0.00	0.00	240.55	27.18	41.49	13.87	323	
Keruing	2.46	5.80	8.26	0.12	3.98	4.10	0.000	0.000	2.826	0.369	0.819	0.082	0.00	0.00	502.97	58.97	128.59	12.04	703	
Selangan	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Selangan Batu	0.00	4.47	4.47	0.00	3.07	3.07	0.000	0.000	2.024	0.460	0.276	0.307	0.00	0.00	356.23	63.94	43.33	45.08	509	
Resak	7.14	19.88	27.02	0.34	13.64	13.97	0.419	0.279	7.406	1.397	3.074	1.397	68.75	45.83	1214.59	229.17	482.65	205.41	2,246	
NON-DIPTEROCARP																				
Merbau/Sepatir	0.24	1.19	1.42	0.01	0.81	0.82	0.000	0.000	0.454	0.247	0.000	0.124	0.00	0.00	142.47	77.71	0.00	18.19	238	
Kembang	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Nyatoh	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Pisang-pisang	0.64	0.00	0.64	0.03	0.00	0.03	0.000	0.000	0.015	0.015	0.000	0.000	0.00	0.00	2.53	2.43	0.00	0.00	5	
Mempening	0.35	0.00	0.35	0.02	0.00	0.02	0.000	0.000	0.008	0.008	0.000	0.000	0.00	0.00	1.35	1.35	0.00	0.00	3	
Medang	0.77	0.72	1.48	0.04	0.49	0.53	0.000	0.000	0.396	0.132	0.000	0.000	0.00	0.00	64.91	21.64	0.00	0.00	87	
Other Timbers	7.24	6.49	13.73	0.34	4.45	4.79	0.144	0.096	2.541	0.479	1.055	0.479	23.59	15.73	416.77	78.64	165.61	70.48	771	
PIONEERS	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
NON-COMMERCIAL*	5.21	0.63	5.84	0.25	0.43	0.68	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Total (EXCLUDE*)	36.02	56.52	92.54	2.03	52.41	54.44							586.73	723.30	5663.58	1441.82	1201.42	680.72	10,298	189.14
Total (INCLUDE*)	41.23	57.15	98.38	2.28	52.85	55.12														
AT YEAR	**20**																			
DIPTEROCARP																				
Red Seraya	11.73	19.69	31.42	0.55	13.51	14.06	0.562	1.125	7.030	2.812	1.265	1.265	239.02	461.32	2444.49	823.19	295.22	276.42	4,540	
White Seraya	13.52	17.16	30.68	0.64	11.77	12.41	1.613	1.737	5.583	1.737	0.993	0.744	685.44	712.36	1941.29	508.46	231.55	162.60	4,242	
Melapi	0.75	0.00	0.75	0.04	0.00	0.04	0.005	0.004	0.016	0.004	0.006	0.001	1.57	1.28	4.30	0.95	1.32	0.23	10	
Yellow Seraya	2.85	5.28	8.13	0.13	3.63	3.76	0.338	0.376	1.616	0.714	0.301	0.413	107.08	113.39	446.74	175.11	70.16	90.32	1,003	
Kapur	0.63	3.12	3.74	0.03	2.14	2.17	0.000	0.000	1.561	0.195	0.304	0.108	0.00	0.00	410.67	46.40	70.83	23.68	552	
Keruing	2.35	6.41	8.77	0.11	4.40	4.51	0.000	0.000	3.112	0.406	0.902	0.090	0.00	0.00	823.20	96.52	210.46	19.71	1,150	
Selangan	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Selangan Batu	0.00	3.73	3.73	0.00	2.56	2.56	0.000	0.000	1.687	0.383	0.230	0.256	0.00	0.00	441.21	79.19	53.67	55.83	630	
Resak	8.73	20.38	29.11	0.41	13.98	14.39	0.432	0.288	7.628	1.439	3.166	1.439	105.22	70.15	1858.96	350.75	738.71	314.39	3,438	
NON-DIPTEROCARP																				
Merbau/Sepatir	0.28	1.11	1.38	0.01	0.76	0.77	0.000	0.000	0.425	0.232	0.000	0.116	0.00	0.00	198.16	108.09	0.00	25.30	332	
Kembang	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Nyatoh	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Pisang-pisang	0.68	0.00	0.68	0.03	0.00	0.03	0.000	0.000	0.016	0.016	0.000	0.000	0.00	0.00	3.98	3.82	0.00	0.00	8	
Mempening	0.96	0.00	0.96	0.05	0.00	0.05	0.000	0.000	0.023	0.023	0.000	0.000	0.00	0.00	5.49	5.49	0.00	0.00	11	
Medang	1.71	0.67	2.38	0.08	0.46	0.54	0.000	0.000	0.406	0.135	0.000	0.000	0.00	0.00	98.83	32.94	0.00	0.00	132	
Other Timbers	8.00	7.53	15.53	0.38	5.17	5.54	0.166	0.111	2.938	0.554	1.220	0.554	40.53	27.02	716.08	135.11	284.55	121.10	1,324	
PIONEERS	0.05	0.00	0.05	0.00	0.00	0.00	0.000	0.000	0.001	0.000	0.000	0.000	0.00	0.00	0.27	0.08	0.11	0.07	1	
NON-COMMERCIAL*	7.90	0.53	8.44	0.37	0.37	0.74	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Total (EXCLUDE*)	44.02	64.70	108.73	2.46	58.37	60.83							1178.86	1385.52	9393.65	2366.10	1956.58	1089.66	17,370	285.57
Total (INCLUDE*)	51.93	65.24	117.16	2.83	58.74	61.56														

SPECIES	GROSS YIELD (m3/ha) 40<60	>60	> 40	NET YIELD (m3/ha) 40<60	>60	> 40	TIMBER YIELD BY GRADES (m3/ha) FAQ	SSQ	SQ	MQ	SM/SSM	MQL	TIMBER VALUE BY GRADES (RM/ha) FAQ	SSQ	SQ	MQ	SM/SSM	MQL	TOTAL RM/ha	MEAN RM/m3
AT YEAR	**40**																			
DIPTEROCARP																				
Red Seraya	9 87	23 74	33 61	0.46	16.29	16 75	0 670	1 340	8 375	3.350	1 508	1.508	423.12	816.66	4327.41	1457.26	522.62	489 33	8,036	
White Seraya	18.07	25 86	43.93	0 85	17.74	18.59	2.417	2 603	8 366	2.603	1.487	1.115	1526 16	1586 09	4322 33	1132 10	515 56	362.04	9,444	
Melapi	0 00	0 57	0 57	0 00	0 39	0 39	0 055	0 047	0.173	0.043	0 063	0 012	25 91	21.17	71.11	15 77	21 83	3 83	160	
Yellow Seraya	2.13	5.64	7.77	0.10	3 87	3 97	0.357	0 397	1.706	0.754	0 317	0.436	167 93	177 83	700 61	274 62	110 02	141 65	1,573	
Kapur	0 88	3 54	4.42	0.04	2 43	2 47	0.000	0 000	1.777	0.222	0.346	0.123	0 00	0.00	694.57	78 48	119 79	40.06	933	
Keruing	1.83	6 70	8 53	0 09	4 60	4 68	0 000	0 000	3 231	0.421	0 936	0 094	0 00	0 00	1269 80	148 88	324.64	30 40	1,774	
Selangan	0.32	0 00	0.32	0.02	0 00	0.02	0 000	0 000	0.010	0 002	0 002	0.001	0 00	0 00	4 01	0 53	0 68	0 42	6	
Selangan Batu	0 00	3.14	3.14	0 00	2 16	2 16	0 000	0 000	1 424	0 324	0 194	0 216	0 00	0 00	553.25	99 31	67 30	70.01	790	
Resak	8 65	23 08	31.73	0 41	15.83	16.24	0 487	0 325	8 607	1.624	3 573	1 624	176 41	117.61	3116.58	588 03	1238 46	527.08	5,764	
NON-DIPTEROCARP																				
Merbau/Sepatir	0 30	1 03	1.33	0.01	0 71	0 72	0 000	0 000	0.398	0 217	0 000	0 108	0 00	0 00	275 74	150 40	0.00	35.21	461	
Kembang	0 00	0 00	0.00	0 00	0 00	0 00	0 000	0.000	0.000	0 000	0.000	0 000	0 00	0 00	0.00	0 00	0.00	0 00	0	
Nyatoh	0.24	0 00	0 24	0 01	0 00	0 01	0 000	0 001	0 004	0.002	0 002	0 002	0 00	0 35	1.77	0 81	0.65	0.61	4	
Pisang-pisang	1 28	0 00	1 28	0 06	0 00	0 06	0 000	0 000	0 031	0.030	0 000	0 000	0 00	0 00	11.12	10 68	0 00	0 00	22	
Mempening	2 14	0 00	2 14	0 10	0.00	0 10	0 000	0 000	0 050	0 050	0.000	0 000	0 00	0 00	18 21	18 21	0 00	0 00	36	
Medang	3 24	0 59	3 83	0 15	0 41	0 56	0 000	0 000	0 419	0 140	0 000	0 000	0 00	0 00	151 90	50 63	0 00	0 00	203	
Other Timbers	11 54	8 41	19 95	0 54	5 77	6 31	0 189	0 126	3 347	0.631	1 389	0 631	68 60	45 73	1211.95	228 67	481.60	204 97	2,242	
PIONEERS	0 10	0 00	0.10	0 00	0 00	0 00	0 000	0 000	0 002	0 001	0 001	0 001	0 00	0 00	0.81	0 25	0 35	0 21	2	
NON-COMMERCIAL*	13 57	0 44	14 00	0 64	0 30	0 94	0 000	0 000	0 000	0 000	0 000	0 000	0 00	0 00	0 00	0 00	0 00	0 00	0	
Total (EXCLUDE*)	52 87	79 24	132 10	2 85	70 19	73 04							2388 13	2765 42	16731 16	4254 63	3403 50	1905 81	31,449	430 59
Total (INCLUDE*)	66 43	79 67	146 10	3 49	70 49	73 97														
AT YEAR	**60**																			
DIPTEROCARP																				
Red Seraya	6 64	27 64	34.28	0 31	18 96	19 27	0 771	1 542	9 637	3 855	1 735	1 735	723 45	1396 31	7398 92	2491 60	893 56	836 65	13,740	
White Seraya	21 57	37 01	58 58	1 01	25 39	26 40	3 432	3 696	11 880	3 696	2 112	1 584	3220 61	3347 07	9121 30	2389 04	1087 97	764 01	19,930	
Melapi	0 23	0 63	0 86	0 01	0 43	0 44	0 062	0 053	0 194	0 049	0 071	0 013	43 16	35 26	118 45	26 27	36 36	6 38	266	
Yellow Seraya	1 42	5 67	7 09	0 07	3 89	3 96	0 356	0 398	1 702	0 752	0 317	0 435	248 89	263 57	1038 42	407 03	163 07	209 94	2,331	
Kapur	1 36	3 35	4 72	0 06	2 30	2 36	0 000	0 000	1 703	0 213	0 331	0 118	0 00	0 00	988 86	111 74	170 55	57 03	1,328	
Keruing	1 81	7 02	8 83	0 09	4 82	4 90	0 000	0 000	3 384	0 441	0 981	0 098	0 00	0 00	1976 23	231 70	505 24	47 31	2,760	
Selangan	0 56	0 00	0 56	0 03	0 00	0 03	0 000	0 000	0 018	0 003	0 003	0 002	0 00	0 00	10 34	1 37	1 76	1 08	15	
Selangan Batu	0 00	2 71	2 71	0 00	1 86	1 86	0 000	0 000	1 226	0 279	0 167	0 186	0 00	0 00	707 81	127 05	86 10	89 57	1,011	
Resak	10 01	24 54	34 55	0 47	16 83	17 30	0 519	0 346	9 170	1 730	3 807	1 730	279 31	186 21	4934 48	931 03	1960 85	834 52	9,126	
NON-DIPTEROCARP																				
Merbau/Sepatir	0 29	0 93	1 22	0 01	0 64	0 65	0 000	0 000	0 357	0 195	0 000	0 097	0 00	0 00	367 77	200 60	0 00	46 96	615	
Kembang	0 13	0 00	0 13	0 01	0 00	0 01	0 000	0 000	0 004	0 002	0 000	0 000	0 00	0 00	2 15	1 01	0 00	0 00	3	
Nyatoh	0 46	0 00	0 46	0 02	0 00	0 02	0 000	0 002	0 008	0 004	0 004	0 004	0 00	1 01	5 18	2 36	1 91	1 78	12	
Pisang-pisang	2 70	0 00	2 70	0 13	0 00	0 13	0 000	0 000	0 065	0 062	0 000	0 000	0 00	0 00	34 79	33 43	0 00	0 00	68	
Mempening	3 46	0 00	3 46	0 16	0 00	0 16	0 000	0 000	0 081	0 081	0 000	0 000	0 00	0 00	43 79	43 79	0 00	0 00	88	
Medang	6 22	0 52	6 74	0 29	0 36	0 65	0 000	0 000	0 489	0 163	0 000	0 000	0 00	0 00	263 34	87 78	0 00	0 00	351	
Other Timbers	14 32	8 63	22 94	0 67	5 92	6 59	0 198	0 132	3 493	0 659	1 450	0 659	106 39	70 93	1879 55	354 63	746 89	317 87	3,476	
PIONEERS	0 06	0 03	0 09	0 00	0 02	0 02	0 000	0 000	0 011	0 003	0 005	0 003	0 00	0 00	6 07	1 86	2 61	1 55	12	
NON-COMMERCIAL*	20 81	0 70	21 50	0 98	0 48	1 46	0 000	0 000	0 000	0 000	0 000	0 000	0 00	0 00	0 00	0 00	0 00	0 00	0	
Total (EXCLUDE*)	62 32	94 14	156 46	3 35	81 41	84 76							4621 81	5300 35	28897 46	7442 29	5656 87	3214 66	55 133	650 46
Total (INCLUDE*)	83 13	94 84	177 96	4 33	81 89	86 22														

Appendix 4.3 Timber stock valuation in units logged by reduced impact logging (RIL)

Assumptions

1)	Proportion of trees 40-60 cm DBH harvested	2	% (based on data from this study).
2)	Proportion of trees 40-60 cm DBH dead after logging	1	% (based on actual data 8-12 months after logging only for crown, stem and bark damage).
3)	Proportion of trees >60 cm DBH dead after logging	4	% (based on actual data 8-12 months after logging only for crown, stem and bark damage).
4)	Annual real price rise for all timber grades	2	% (based on ITTO report, 1993).
5)	Proportion of utilizable wood	70	% (Bhargava and Kugan, 1988)

		TIMBER GRADES PROPORTION (%)						TIMBER PRICE BY GRADES (RM/m3)					
		FAQ	SSQ	SQ	MQ	SM/SSM	MQL	FAQ	SSQ	SQ	MQ	SM/SSM	MQL
COMMERCIAL	*DIPTEROCARP*												
	Red Seraya	4	8	50	20	9	9	286	276	234	197	157	147
	White Seraya	13	14	45	14	8	6	286	276	234	197	157	147
	Melapi	14	12	44	11	16	3	213	203	186	165	157	147
	Yellow Seraya	9	10	43	19	8	11	213	203	186	165	157	147
	Kapur	0	0	72	9	14	5	0	0	177	160	157	147
	Keruing	0	0	69	9	20	2	0	0	178	160	157	147
	Selangan	0	0	68	10	13	9	0	0	176	159	157	139
	Selangan Batu	0	0	66	15	9	10	0	0	176	139	157	147
	Resak	3	2	53	10	22	10	164	164	164	164	157	147
	NON-DIPTEROCARP												
	Merbau/Sepatir	0	0	55	30	0	15	314	314	314	314	157	147
	Kembang	0	0	68	32	0	0	164	164	164	164	157	147
	Nyatoh	0	7	39	20	17	17	213	203	186	165	157	147
	Pisang-pisang	0	0	51	49	0	0	164	164	164	164	157	147
	Mempening	0	0	50	50	0	0	164	164	164	164	157	147
	Medang	0	0	75	25	0	0	164	164	164	164	157	147
	Other Timbers	3	2	53	10	22	10	164	164	164	164	157	147
	PIONEERS	0	0	49	15	22	14	164	164	164	164	157	147
NON-COMMERCIAL	timbers	0	0	0	0	0	0	0	0	0	0	0	0

SPECIES	GROSS YIELD (m3/ha)			NET YIELD (m3/ha)			TIMBER YIELD BY GRADES (m3/ha)						TIMBER VALUE BY GRADES (RM/ha)						TOTAL	MEAN
	40-60	>60	> 40	40-60	>60	> 40	FAQ	SSQ	SQ	MQ	SM/SSM	MQL	FAQ	SSQ	SQ	MQ	SM/SSM	MQL	RM/ha	RM/m3
AT YEAR	**0**																			
DIPTEROCARP																				
Red Seraya	3 80	43.49	47 29	0 05	29.22	29 28	1 171	2 342	14 638	5.855	2.635	2.635	334 91	646.41	3425.25	1153 46	413 67	387 32	6,361	
White Seraya	10.94	43.74	54 67	0.15	29 39	29.54	3.840	4.136	13.294	4.136	2.363	1 773	1098.36	1141.49	3110 74	814 76	371.04	260 56	6,797	
Melapi	0 00	0.00	0.00	0 00	0 00	0.00	0 000	0 000	0 000	0.000	0 000	0 000	0.00	0 00	0 00	0 00	0 00	0 00	0	
Yellow Seraya	0.00	9.93	9 93	0.00	6 67	6.67	0.600	0 667	2 869	1 268	0 534	0.734	127 90	135.44	533 64	209 17	83 80	107 89	1,198	
Kapur	2.05	0 00	2 05	0 03	0 00	0.03	0.000	0.000	0.020	0 003	0.004	0 001	0 00	0.00	3 62	0 41	0 62	0 21	5	
Keruing	0 00	0.00	0 00	0 00	0 00	0 00	0 000	0 000	0.000	0 000	0.000	0 000	0.00	0.00	0 00	0 00	0.00	0 00	0	
Selangan	0 00	2 46	2 46	0 00	1.65	1.65	0 000	0 000	1.123	0.165	0 215	0 149	0.00	0.00	197.60	26.25	33 70	20 66	278	
Selangan Batu	0 86	1 25	2 11	0.01	0.84	0 85	0.000	0 000	0 563	0 128	0 077	0 085	0 00	0.00	99 05	17 78	12 05	12 53	141	
Resak	3 87	36 07	39 94	0 05	24.24	24 29	0 729	0 486	12.876	2 429	5 345	2 429	119 53	79 68	2111 62	398 42	839 11	357.12	3,905	
NON-DIPTEROCARP																				
Merbau/Sepatir	0 00	2 93	2 93	0.00	1 97	1 97	0 000	0 000	1 082	0 590	0.000	0 295	0.00	0.00	339 65	185 26	0 00	43 37	568	
Kembang	1 30	0 00	1 30	0 02	0 00	0 02	0 000	0 000	0 012	0 006	0 000	0 000	0 00	0 00	2 01	0 95	0 00	0 00	3	
Nyatoh	0 00	0 00	0 00	0 00	0 00	0 00	0.000	0 000	0.000	0 000	0.000	0 000	0.00	0.00	0 00	0 00	0 00	0 00	0	
Pisang-pisang	0 00	0 00	0.00	0.00	0 00	0 00	0 000	0 000	0 000	0 000	0 000	0 000	0 00	0 00	0 00	0 00	0 00	0 00	0	
Mempening	0 88	0 00	0 88	0.01	0 00	0 01	0 000	0 000	0 006	0 006	0 000	0 000	0 00	0 00	1 00	1 00	0 00	0 00	2	
Medang	1 41	0 98	2 39	0 02	0 66	0 68	0 000	0.000	0 507	0 169	0 000	0 000	0.00	0 00	83 13	27 71	0 00	0 00	111	
Other Timbers	6 87	8 72	15 59	0 10	5 86	5 96	0 179	0 119	3 157	0 596	1 310	0 596	29 30	19 54	517 69	97 68	205 72	87 55	957	
PIONEERS	0.84	0 00	0 84	0 01	0 00	0 01	0 000	0 000	0 006	0 002	0 003	0 002	0.00	0 00	0 94	0 29	0 40	0 24	2	
NON-COMMERCIAL*	9 48	5 72	15 19	0 13	3 84	3 97	0 000	0 000	0 000	0 000	0 000	0 000	0 00	0 00	0 00	0 00	0 00	0 00	0	
Total (EXCLUDE*)	28 94	113 48	142 42	0 45	100 50	100 96							1710 01	2022 56	10425 93	2933 13	1960 11	1277 44	20,329	201 37
Total (INCLUDE*)	38 41	119 20	157 61	0 59	104 34	104 93														
AT YEAR	**20**																			
DIPTEROCARP																				
Red Seraya	5 01	43 43	48 45	0 07	29 19	29 26	1 170	2 341	14 629	5 852	2 633	2 633	497 36	959 93	5086 59	1712 92	614 30	575 18	9,446	
White Seraya	14 46	45 29	59 75	0 20	30 43	30 63	3 982	4 289	13 785	4 289	2 451	1 838	1692 48	1758 94	4793 38	1255 47	571 75	401 50	10,474	
Melapi	0 00	0 00	0 00	0 00	0 00	0 00	0 000	0 000	0 000	0 000	0 000	0 000	0 00	0 00	0 00	0 00	0 00	0 00	0	
Yellow Seraya	0 00	9 23	9 23	0 00	6 20	6 20	0 558	0 620	2 667	1 178	0 496	0 682	176 68	187 10	737 15	288 94	115 76	149 03	1,655	
Kapur	0 00	1 43	1 43	0 00	0 96	0 96	0 000	0 000	0 691	0 086	0 134	0 048	0 00	0 00	181 77	20 54	31 35	10 48	244	
Keruing	0 00	1 18	1 18	0 00	0 79	0 79	0 000	0 000	0 547	0 071	0 159	0 016	0 00	0 00	144 69	16 96	36 99	3 46	202	
Selangan	0 00	1 04	1 04	0 00	0 70	0 70	0 000	0 000	0 474	0 070	0 091	0 063	0 00	0 00	123 90	16 46	21 13	12 95	174	
Selangan Batu	1 42	1 16	2 58	0 02	0 78	0 80	0 000	0 000	0 525	0 119	0 072	0 080	0 00	0 00	137 42	24 67	16 72	17 39	196	
Resak	7 25	34 07	41 31	0 10	22 89	23 00	0 690	0 460	12 188	2 300	5 059	2 300	168 12	112 08	2970 04	560 38	1180 22	502 30	5,493	
NON-DIPTEROCARP																				
Merbau/Sepatir	0 20	2 34	2 54	0 00	1 57	1 58	0 000	0 000	0 867	0 473	0 000	0 236	0 00	0 00	404 54	220 66	0 00	51 65	677	
Kembang	1 43	0 00	1 43	0 02	0 00	0 02	0 000	0 000	0 013	0 006	0 000	0 000	0 00	0 00	3 27	1 54	0 00	0 00	5	
Nyatoh	0 00	0 00	0 00	0 00	0 00	0 00	0 000	0 000	0 000	0 000	0 000	0 000	0 00	0 00	0 00	0 00	0 00	0 00	0	
Pisang-pisang	0 00	0 00	0 00	0 00	0 00	0 00	0 000	0 000	0 000	0 000	0 000	0 000	0 00	0 00	0 00	0 00	0 00	0 00	0	
Mempening	2 06	0 00	2 06	0 03	0 00	0 03	0 000	0 000	0 014	0 014	0 000	0 000	0 00	0 00	3 47	3 47	0 00	0 00	7	
Medang	2 82	0 89	3 70	0 04	0 60	0 64	0 000	0 000	0 477	0 159	0 000	0 000	0 00	0 00	116 30	38 77	0 00	0 00	155	
Other Timbers	8 54	10 72	19 26	0 12	7 20	7 32	0 220	0 146	3 880	0 732	1 611	0 732	53 52	35 68	945 60	178 41	375 76	159 92	1,749	
PIONEERS	0 00	0 57	0 57	0 00	0 38	0 38	0 000	0 000	0 188	0 057	0 084	0 054	0 00	0 00	45 77	14 01	19 67	11 72	91	
NON-COMMERCIAL*	12 57	4 74	17 31	0 17	3 18	3 36	0 000	0 000	0 000	0 000	0 000	0 000	0 00	0 00	0 00	0 00	0 00	0 00	0	
Total (EXCLUDE*)	35 93	117 27	153 20	0 80	101 70	102 30							2588 16	3053 73	15693 88	4353 21	2983 65	1895 58	30,568	298 81
Total (INCLUDE*)	48 50	122 01	170 51	0 77	104 88	105 66														

SPECIES	GROSS YIELD (m3/ha)			NET YIELD (m3/ha)			TIMBER YIELD BY GRADES (m3/ha)						TIMBER VALUE BY GRADES (RM/ha)						TOTAL	MEAN
	40-60	>60	> 40	40-60	>60	> 40	FAQ	SSQ	SQ	MQ	SM/SSM	MQL	FAQ	SSQ	SQ	MQ	SM/SSM	MQL	RM/ha	RM/m3
AT YEAR	**40**																			
DIPTEROCARP																				
Red Seraya	7.35	42.98	50.32	0.10	28.88	28.98	1.159	2.319	14.492	5.797	2.608	2.608	732.11	1413.02	7487.49	2521.43	904.26	846.66	13,905	
White Seraya	16.33	50.51	66.83	0.23	33.94	34.17	4.442	4.783	15.376	4.783	2.733	2.050	2805.00	2915.15	7944.24	2080.74	947.58	665.41	17,358	
Melapi	0.25	0.00	0.25	0.00	0.00	0.00	0.000	0.000	0.001	0.000	0.001	0.000	0.22	0.18	0.61	0.14	0.19	0.03	1	
Yellow Seraya	0.00	8.27	8.27	0.00	5.56	5.56	0.500	0.556	2.390	1.056	0.445	0.611	235.23	249.09	981.39	384.68	154.12	198.41	2,203	
Kapur	0.55	1.42	1.97	0.01	0.95	0.96	0.000	0.000	0.693	0.087	0.135	0.048	0.00	0.00	270.70	30.59	46.69	15.61	364	
Keruing	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Selangan	0.00	2.02	2.02	0.00	1.36	1.36	0.000	0.000	0.922	0.136	0.176	0.122	0.00	0.00	358.12	47.58	61.07	37.43	504	
Selangan Batu	0.86	1.54	2.40	0.01	1.04	1.05	0.000	0.000	0.692	0.157	0.094	0.105	0.00	0.00	268.84	48.25	32.70	34.02	384	
Resak	7.82	35.22	43.03	0.11	23.66	23.77	0.713	0.475	12.600	2.377	5.230	2.377	258.26	172.17	4562.59	860.87	1813.07	771.63	8,439	
NON-DIPTEROCARP																				
Merbau/Sepatir	0.22	1.87	2.09	0.00	1.26	1.26	0.000	0.000	0.694	0.378	0.000	0.189	0.00	0.00	480.87	262.29	0.00	61.40	805	
Kembang	1.40	0.00	1.40	0.02	0.00	0.02	0.000	0.000	0.013	0.006	0.000	0.000	0.00	0.00	4.76	2.24	0.00	0.00	7	
Nyatoh	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Pisang-pisang	0.15	0.00	0.15	0.00	0.00	0.00	0.000	0.000	0.001	0.001	0.000	0.000	0.00	0.00	0.38	0.37	0.00	0.00	1	
Mempening	4.14	0.00	4.14	0.06	0.00	0.06	0.000	0.000	0.029	0.029	0.000	0.000	0.00	0.00	10.38	10.38	0.00	0.00	21	
Medang	5.22	0.84	6.06	0.07	0.56	0.63	0.000	0.000	0.476	0.159	0.000	0.000	0.00	0.00	172.39	57.46	0.00	0.00	230	
Other Timbers	14.82	11.54	26.36	0.21	7.76	7.96	0.239	0.159	4.220	0.796	1.752	0.796	86.51	57.67	1528.27	288.35	607.30	258.46	2,827	
PIONEERS	0.07	0.63	0.70	0.00	0.42	0.42	0.000	0.000	0.208	0.064	0.093	0.059	0.00	0.00	75.16	23.01	32.31	19.25	150	
NON-COMMERCIAL*	21.41	4.19	25.60	0.30	2.81	3.11	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Total (EXCLUDE*)	51.74	121.62	173.35	0.82	105.39	106.21							4117.33	4807.29	24146.20	6618.38	4599.28	2908.33	47,197	444.37
Total (INCLUDE*)	73.15	125.80	198.95	1.12	108.21	109.32														
AT YEAR	**60**																			
DIPTEROCARP																				
Red Seraya	8.97	41.35	50.31	0.12	27.78	27.91	1.116	2.233	13.955	5.582	2.512	2.512	1047.57	2021.88	10713.78	3607.89	1293.89	1211.48	19,896	
White Seraya	22.89	58.01	80.90	0.32	38.98	39.30	5.109	5.502	17.685	5.502	3.144	2.358	4794.23	4982.49	13578.06	3556.34	1619.57	1137.31	29,668	
Melapi	0.86	0.00	0.86	0.01	0.00	0.01	0.002	0.001	0.005	0.001	0.002	0.000	1.17	0.95	3.20	0.71	0.98	0.17	7	
Yellow Seraya	0.20	6.74	6.94	0.00	4.53	4.53	0.408	0.453	1.949	0.861	0.363	0.499	285.07	301.88	1189.37	466.20	186.78	240.46	2,670	
Kapur	0.65	1.40	2.04	0.01	0.94	0.95	0.000	0.000	0.683	0.085	0.133	0.047	0.00	0.00	396.42	44.79	68.37	22.86	532	
Keruing	0.56	0.00	0.56	0.01	0.00	0.01	0.000	0.000	0.005	0.001	0.002	0.000	0.00	0.00	3.11	0.37	0.80	0.07	4	
Selangan	0.00	1.77	1.77	0.00	1.19	1.19	0.000	0.000	0.809	0.119	0.155	0.107	0.00	0.00	466.96	62.04	79.63	48.81	657	
Selangan Batu	0.86	1.41	2.27	0.01	0.94	0.96	0.000	0.000	0.631	0.143	0.086	0.096	0.00	0.00	364.56	65.44	44.35	46.13	520	
Resak	9.98	35.58	45.56	0.14	23.91	24.05	0.721	0.481	12.745	2.405	5.290	2.405	388.19	258.80	6858.10	1293.98	2725.25	1159.85	12,684	
NON-DIPTEROCARP																				
Merbau/Sepatir	0.24	1.52	1.76	0.00	1.02	1.03	0.000	0.000	0.564	0.308	0.000	0.154	0.00	0.00	581.01	316.91	0.00	74.18	972	
Kembang	0.16	0.86	1.02	0.00	0.58	0.58	0.000	0.000	0.396	0.186	0.000	0.000	0.00	0.00	212.98	100.23	0.00	0.00	313	
Nyatoh	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Pisang-pisang	0.65	0.00	0.65	0.01	0.00	0.01	0.000	0.000	0.005	0.004	0.000	0.000	0.00	0.00	2.45	2.36	0.00	0.00	5	
Mempening	6.30	0.00	6.30	0.09	0.00	0.09	0.000	0.000	0.044	0.044	0.000	0.000	0.00	0.00	23.49	23.49	0.00	0.00	47	
Medang	7.63	0.75	8.37	0.11	0.50	0.61	0.000	0.000	0.456	0.152	0.000	0.000	0.00	0.00	245.37	81.79	0.00	0.00	327	
Other Timbers	19.97	12.93	32.90	0.28	8.69	8.97	0.269	0.179	4.752	0.897	1.973	0.897	144.75	96.50	2557.23	482.50	1016.18	432.48	4,730	
PIONEERS	0.17	0.64	0.80	0.00	0.43	0.43	0.000	0.000	0.210	0.064	0.094	0.060	0.00	0.00	113.18	34.65	48.65	28.99	225	
NON-COMMERCIAL*	33.81	3.59	37.40	0.47	2.41	2.88	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0	
Total (EXCLUDE*)	70.99	127.37	198.36	1.11	109.50	110.61							6660.98	7662.50	37309.27	#######	7084.45	4402.80	73,260	662.32
Total (INCLUDE*)	104.81	130.98	235.76	1.58	111.91	113.49														

Appendix 4.4 Percentage of timber volume in each log grade for each species/species group in Coupe YL2/1993 and YL2/1994 adjacent to the study area (RBJ, 1993).

	FAQ		SSQ		SQ		MQ		SM/SSM		MQL		RJ		Total	
	m3	%	m3	%	m3	%	m3	%	m3	%	m3	%	m3	%	m3	%
Coupe: C93-YL2- 1993																
DIPTEROCARP																
Red Seraya	955	4	1628	7	11305	49	5174	22	1688	7	2451	11	12	0 05	23118	100
White Seraya	5071	14	5017	14	15462	43	5640	16	2521	7	2420	7	0	0	36016	100
Melapi	116	16	90	13	304	43	110	15	84	12	6	1	0	0	710	100
Yellow Seraya	502	8	634	10	2506	41	1315	22	347	6	749	12	14	0 23	6054	100
Kapur	0	0	0	0	1930	69	290	10	417	15	145	5	0	0	2783	100
Keruing	0	0	0	0	1314	71	183	10	294	16	70	4	0	0	1852	100
Selangan	0	0	0	0	136	68	19	10	26	13	20	10	0	0	200	100
Selangan Batu	0	0	0	0	335	63	81	15	35	7	76	14	0	0	529	100
Resak	1	3	0	2	13	53	2	10	5	22	2	9	0 2	1	24	100
Sub-total	6645	9	7369	10	33303	47	12816	18	5418	8	5939	8	26	0 04	71287	100
NON-DIPTEROCARP																
Merbau/Sepatir	0	0	0	0	17	55	9	30	0	0	5	15	0	0	31	100
Kembang	0	0	0	0	12	68	6	32	0	0	0	0	0	0	18	100
Nyatoh	0	0	0	0	20	50	10	25	5	13	5	13	0	0	41	100
Pisang-pisang	0	0	0	0	18	60	12	40	0	0	0	0	0	0	30	100
Mempening	0	0	0	0	13	50	13	50	0	0	0	0	0	0	26	100
Medang	0	0	0	0	19	75	6	25	0	0	0	0	0	0	25	100
Other Timbers	89	5	18	1	836	47	142	8	480	27	213	12	0	0	1779	100
Sub-total	111	5	30	1	1082	48	260	11	528	23	251	11	0	0	2263	100
PIONEERS	0	0	0	0	93	53	28	16	12	7	42	24	0	0	178	100
Total	6756	9	7400	10	34478	47	13104	18	5959	8	6233	8	26	0 03	73725	
Coupe: C94-YL2-1994																
DIPTEROCARP																
Red Seraya	516	4	1356	9	7461	52	2426	17	1509	11	1173	8	0	0	14375	100
White Seraya	2064	12	2490	15	8114	48	1972	12	1519	9	770	5	0	0	16929	100
Melapi	80	11	87	12	328	45	43	6	155	21	43	6	0	0	737	100
Yellow Seraya	436	9	491	10	2140	44	781	16	505	10	484	10	0	0	4820	100
Kapur	0	0	0	0	2104	75	217	8	371	13	114	4	0	0	2806	100
Keruing	0	0	0	0	876	67	98	7	328	25	13	1	0	0	1317	100
Selangan	0	0	0	0	427	68	61	10	81	13	62	10	0	0	630	100
Selangan Batu	0	0	0	0	447	69	93	14	75	12	31	5	0	0	648	100
Resak	2	3	1	2	27	53	5	10	11	22	5	10	0	0	50	100
Sub-total	3097	7	4424	10	21924	52	5697	13	4553	11	2696	6	0	0	42313	100
NON-DIPTEROCARP																
Merbau/Sepatir	0	0	0	0	27	56	14	29	0	0	7	14	0	0	48	100
Kembang	0	0	0	0	12	68	6	32	0	0	0	0	0	0	18	100
Nyatoh	0	0	5	14	10	28	5	14	6	16	5	15	5	13	37	100
Pisang-pisang	0	0	0	0	10	40	16	60	0	0	0	0	0	0	26	100
Mempening	0	0	0	0	4	50	4	50	0	0	0	0	0	0	7	100
Medang	0	0	0	0	27	75	9	25	0	0	0	0	0	0	36	100
Other Timbers	0	0	25	3	536	65	115	14	99	12	49	6	0	0	825	100
Sub-total	0	0	37	3	735	63	189	16	129	11	73	6	5	0 41	1169	100
PIONEERS	0	0	0	0	55	44	18	14	53	42	0	0	0	0	125	100
Total	3097	7	4461	10	22715	52	5904	14	4734	11	2769	6	5	0 01	43606	
TOTAL OF COUPE YL2/1993 AND YL2/1994																
DIPTEROCARP																
Red Seraya	1471	4	2983	8	18765	50	7600	20	3197	9	3624	10	12	0 03	37493	100
White Seraya	7135	13	7507	14	23576	45	7612	14	4040	8	3191	6	0	0	52945	100
Melapi	197	14	177	12	632	44	153	11	239	16	50	3	0	0	1447	100
Yellow Seraya	938	9	1125	10	4646	43	2097	19	852	8	1233	11	14	0 13	10874	100
Kapur	0	0	0	0	4034	72	507	9	788	14	259	5	0	0	5588	100
Keruing	0	0	0	0	2190	69	281	9	623	20	83	3	0	0	3169	100
Selangan	0	0	0	0	563	68	80	10	107	13	82	10	0	0	830	100
Selangan Batu	0	0	0	0	782	66	175	15	109	9	107	9	0	0	1177	100
Resak	2	3	1	2	39	53	7	10	16	22	7	10	0	0	74	100
Sub-total	9743	9	11793	10	55227	49	18513	16	9971	9	8636	8	26	0 02	113599	100
NON-DIPTEROCARP																
Merbau/Sepatir	0	0	0	0	44	55	23	29	0	0	11	14	0	0	79	100
Kembang	0	0	0	0	24	68	11	32	0	0	0	0	0	0	36	100
Nyatoh	0	0	5	7	30	39	15	20	11	14	10	13	5	6	78	100
Pisang-pisang	0	0	0	0	28	51	28	49	0	0	0	0	0	0	56	100
Mempening	0	0	0	0	17	50	17	50	0	0	0	0	0	0	33	100
Medang	0	0	0	0	46	75	15	25	0	0	0	0	0	0	61	100
Other Timbers	89	3	43	2	1372	53	258	10	579	22	263	10	0	0	2603	100
Sub-total	90	3	49	2	1584	53	373	12	602	20	290	10	5	0 16	2994	100
PIONEERS	0	0	0	0	148	49	46	15	65	22	42	14	0	0	301	100
Grand Total	9833	8	11842	10	56960	49	18932	16	10638	9	8968	8	30	0 03	116894	

Note: FAQ=Fair Average Quality; SSQ: Superior Sawmill Quality, SQ Sawmill Quality MQ=Millable Quality SM/SSM Small/Super Small Quality· MQL: Millable Quality: RJ=Reject

Appendix 4.5 Value of timber from first harvest (year 0) in the CL and RIL units

1 Harvest yield using CL 136 m3 ha^{-1}

2 Harvest yield uisng RIL 106 m3 ha^{-1}

3 Harvest yield by species in CL and RIL units (%)

Dipterocarp	**CL**	**RIL**
Red seraya	30.60	30.38
White seraya	32.51	25.77
Melapi	0.55	0.00
Yellow seraya	3.28	6.73
Kapur	2.73	3.27
Keruing	0.55	2.88
Selangan	0.00	1.64
Selangan batu	1.09	1.65
Non Dipterocarp		
Nyatoh	0.27	0.19
Mempening	1.00	1.54
Other timbers	27.60	25.96
	100	100

4 Timber grade in percent

Dipterocarp	**FAQ**	**SSQ**	**SQ**	**MQ**	**SM**	**MQL**
Red seraya	4	8	50	20	9	9
White seraya	13	14	45	14	8	6
Melapi	14	12	44	11	16	3
Yellow seraya	9	10	43	19	8	11
Kapur	0	0	72	9	14	5
Keruing	0	0	69	9	20	2
Selangan	0	0	68	10	13	9
Selangan batu	0	0	66	15	9	10
Non Dipterocarp						
Nyatoh	0	7	39	20	17	17
Mempening	0	0	50	50	0	0
Other timbers	0	0	53	10	22	10

5 Log price (RM m^{-3})

	FAQ	**SSQ**	**SQ**	**MQ**	**SM**	**MQL**
Dipterocarp	286	276	234	197	157	147
Red seraya	286	276	234	197	157	147
White seraya	213	203	186	165	157	147
Melapi	213	203	177	165	157	147
Yellow seraya	0	0	178	160	157	147
Kapur	0	0	176	160	157	147
Keruing	0	0	176	159	157	139
Selangan	0	0	176	139	157	147
Selangan batu	164	164	164	164	157	147
Non Dipterocarp						
Nyatoh	213	186	165	165	157	147
Mempening	164	164	164	164	157	147
Other timbers	164	164	164	164	157	147

6 Yield calculations by species and grades

	CL							RIL						
	FAQ	SSQ	SQ	MQ	SM	MQL	Total	FAQ	SSQ	SQ	MQ	SM	MQL	Total
Dipterocarp														
Red seraya	1.66	3.33	20.81	8.32	3.75	3.75	42	1.29	2.58	16.10	6.44	2.90	2.90	32
White seraya	5.75	6.19	19.90	6.19	3.54	2.65	44	3.55	3.82	12.29	3.82	2.19	1.64	27
Melapi	0.10	0.09	0.33	0.08	0.12	0.02	1	0.00	0.00	0.00	0.00	0.00	0.00	0
Yellow seraya	0.40	0.45	1.92	0.85	0.36	0.49	4	0.64	0.71	3.07	1.36	0.57	0.78	7
Kapur	0.00	0.00	2.67	0.33	0.52	0.19	4	0.00	0.00	2.50	0.31	0.49	0.17	3
Keruing	0.00	0.00	0.52	0.07	0.15	0.01	1	0.00	0.00	2.11	0.27	0.61	0.06	3
Selangan	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	1.18	0.17	0.23	0.16	2
Selangan batu	0.00	0.00	0.98	0.22	0.13	0.15	1	0.00	0.00	1.15	0.26	0.16	0.17	2
Non Dipterocarp														
Nyatoh	0.00	0.03	0.14	0.07	0.06	0.06	0	0.00	0.01	0.08	0.04	0.03	0.03	0
Mempening	0.00	0.00	0.68	0.68	0.00	0.00	1	0.00	0.00	0.82	0.82	0.00	0.00	2
Other timbers	0.00	0.00	19.89	3.75	8.26	3.75	36	0.00	0.00	14.58	2.75	6.05	2.75	26
							134							105

7 Total value by species and grades

	CL							RIL						
	FAQ	SSQ	SQ	MQ	SM	MQL	Total	FAQ	SSQ	SQ	MQ	SM	MQL	Total
Dipterocarp														
Red seraya	476	919	4,869	1,640	588	551	9,042	368	711	3,768	1,269	455	426	6,997
White seraya	1,644	1,708	4,656	1,219	555	390	10,173	1,016	1,055	2,876	753	343	241	6,285
Melapi	22	18	61	14	19	3	137	0	0	0	0	0	0	0
Yellow seraya	86	91	340	140	56	72	784	137	145	543	224	90	115	1,253
Kapur	0	0	476	53	82	27	638	0	0	444	50	76	25	596
Keruing	0	0	91	11	23	2	127	0	0	371	44	96	9	520
Selangan	0	0	0	0	0	0	0	0	0	208	28	35	22	293
Selangan batu	0	0	172	31	21	22	246	0	0	203	36	25	26	290
Non Dipterocarp														
Nyatoh	0	5	24	12	10	9	60	0	3	13	7	5	5	33
Mempening	0	0	112	112	0	0	223	0	0	134	134	0	0	268
Other timbers	0	0	3,263	616	1,296	552	5,726	0	0	2,392	451	950	405	4,198
							27,156							20,732
8 Sales revenue per m³							**200**							**196**

Appendix 5.1 Summary statistics of total biomass, necromass, carbon stock, and flows

Time	Total mass (Mg ha^{-1})							Carbon stock (Mg ha^{-1})			Carbon flows/fluxes			Mean carbon storage			Statistics			
(Yr)	RIL			(A) CL			RIL-CL	RIL	(B) CL	RIL-CL	RIL	(C) CL	RIL-CL	RIL	(D) CL	RIL-CL				
-0	433.0			438.0				213.0	215.5					213.0	215.5		<---- Pre-logging			
-1	21.5		0.97	30.5													<---- Biomass in extracted timber			
1	373.4	351.9	21.50	362.0	331.5	30.5	11.4	183.7	178.1	5.6	-29.33	-37.38	8.05	-14.67	-18.69	4.03				
2	370.1	349.3	20.86	340.6	311.1	29.6	29.5	182.1	167.6	14.5	-1.60	-10.52	8.91	-22.40	-30.67	8.27		RIL	CL	RIL-CL
3	368.9	348.7	20.23	323.8	295.1	28.7	45.1	181.5	159.3	22.2	-0.59	-8.27	7.69	-25.34	-37.79	12.45				
4	357.9	338.3	19.62	303.4	275.5	27.8	54.5	176.1	149.3	26.8	-5.44	-10.07	4.63	-27.57	-43.64	16.08	Flow summation			
5	347.8	328.8	19.03	285.8	258.8	27.0	62.0	171.1	140.6	30.5	-4.96	-8.65	3.69	-29.94	-49.03	19.09	Y 0-20	-62.77	-108.96	46.20
6	338.5	320.1	18.46	270.7	244.5	26.2	67.8	166.6	133.2	33.4	-4.55	-7.41	2.86	-32.32	-53.96	21.64	Y0-40	-33.88	-78.52	44.63
7	330.9	313.0	17.91	258.4	233.0	25.4	72.5	162.8	127.2	35.7	-3.76	-6.05	2.29	-34.61	-58.44	23.83	Y0-60	0.59	-41.96	42.55
8	324.6	307.2	17.37	248.4	223.8	24.6	76.2	159.7	122.2	37.5	-3.10	-4.93	1.83	-36.75	-62.48	25.73				
9	319.4	302.6	16.85	240.3	216.4	23.9	79.1	157.2	118.2	38.9	-2.54	-3.99	1.45	-38.74	-66.13	27.39	Mean Carbon Storage			
10	315.2	298.9	16.34	233.8	210.6	23.2	81.5	155.1	115.0	40.1	-2.07	-3.22	1.15	-40.55	-69.40	28.85	Total carbon			
11	311.9	296.0	15.85	228.5	206.0	22.5	83.3	153.4	112.4	41.0	-1.66	-2.57	0.91	-42.21	-72.34	30.13	Y 0-20	-51.37	-88.36	36.99
12	309.2	293.8	15.38	224.4	202.6	21.8	84.8	152.1	110.4	41.7	-1.31	-2.02	0.72	-43.71	-74.99	31.28	Y0-40	-51.25	-92.57	41.32
13	307.2	292.3	14.92	221.3	200.1	21.2	85.9	151.1	108.9	42.3	-1.00	-1.56	0.56	-45.07	-77.36	32.29	Y0-60	-39.17	-81.22	42.04
14	305.7	291.2	14.47	218.9	198.4	20.5	86.8	150.4	107.7	42.7	-0.73	-1.16	0.43	-46.30	-79.50	33.19				
15	304.7	290.7	14.04	217.2	197.3	19.9	87.5	149.9	106.9	43.0	-0.49	-0.82	0.33	-47.41	-81.41	34.00	PTE over 20 yrs			
16	304.1	290.5	13.61	216.2	196.8	19.3	88.0	149.6	106.3	43.3	-0.28	-0.52	0.24	-48.40	-83.13	34.73	2%	-57.98	-100.35	42.37
17	304.0	290.8	13.21	215.6	196.9	18.7	88.4	149.5	106.1	43.5	-0.09	-0.27	0.18	-49.28	-84.67	35.38	4%	-53.88	-92.98	39.10
18	304.1	291.3	12.81	215.5	197.3	18.2	88.6	149.6	106.0	43.6	0.09	-0.04	0.13	-50.07	-86.04	35.97	6%	-50.34	-86.62	36.28
19	304.6	292.2	12.43	215.8	198.2	17.6	88.8	149.9	106.2	43.7	0.25	0.16	0.08	-50.76	-87.27	36.51	8%	-47.28	-81.09	33.81
20	305.4	293.4	12.05	216.5	199.4	17.1	88.9	150.3	106.5	43.7	0.39	0.34	0.05	-51.37	-88.36	36.99	10%	-44.60	-76.26	31.65
21	306.5	294.8	11.69	217.6	201.0	16.6	88.9	150.8	107.0	43.8	0.53	0.51	0.02	-51.90	-89.33	37.43				
22	307.8	296.5	11.34	218.9	202.8	16.1	88.9	151.5	107.7	43.8	0.65	0.66	0.00	-52.36	-90.19	37.83	PTE over 40 yrs			
23	309.4	298.4	11.00	220.5	204.9	15.6	88.9	152.2	108.5	43.7	0.78	0.79	-0.02	-52.74	-90.94	38.19	2%	-42.70	-84.26	41.56
24	311.2	300.5	10.67	222.4	207.2	15.1	88.8	153.1	109.4	43.7	0.88	0.92	-0.04	-53.06	-91.59	38.53	4%	-45.60	-84.27	38.67
25	313.2	302.9	10.35	224.5	209.8	14.7	88.7	154.1	110.5	43.7	0.99	1.04	-0.05	-53.31	-92.15	38.83	6%	-45.76	-81.81	36.05
26	315.5	305.4	10.04	226.8	212.6	14.2	88.6	155.2	111.6	43.6	1.10	1.15	-0.05	-53.51	-92.62	39.11	8%	-44.68	-78.37	33.69
27	317.9	308.1	9.74	229.4	215.6	13.8	88.5	156.4	112.9	43.5	1.19	1.26	-0.07	-53.65	-93.01	39.37	10%	-43.10	-74.69	31.58
28	320.5	311.1	9.45	232.2	218.8	13.4	88.3	157.7	114.2	43.5	1.29	1.36	-0.07	-53.73	-93.33	39.60				
29	323.3	314.1	9.16	235.1	222.1	13.0	88.2	159.1	115.7	43.4	1.37	1.46	-0.09	-53.76	-93.58	39.82	PTE over 60 yrs			
30	326.3	317.4	8.89	238.3	225.7	12.6	88.0	160.5	117.2	43.3	1.46	1.54	-0.09	-53.75	-93.76	40.02	2%	-29.69	-70.47	40.78
31	329.4	320.8	8.62	241.6	229.4	12.2	87.8	162.1	118.9	43.2	1.54	1.64	-0.09	-53.68	-93.88	40.20	4%	-40.54	-78.91	38.37
32	332.7	324.3	8.36	245.1	233.2	11.9	87.6	163.7	120.6	43.1	1.62	1.72	-0.10	-53.57	-93.94	40.37	6%	-43.73	-79.66	35.92
33	336.1	328.0	8.11	248.7	237.2	11.5	87.4	165.4	122.4	43.0	1.69	1.79	-0.10	-53.42	-93.94	40.52	8%	-43.85	-77.49	33.64
34	339.7	331.9	7.87	252.6	241.4	11.2	87.2	167.1	124.3	42.9	1.77	1.88	-0.11	-53.22	-93.89	40.67	10%	-42.75	-74.31	31.56
35	343.5	335.8	7.63	256.5	245.7	10.8	87.0	169.0	126.2	42.8	1.84	1.95	-0.11	-52.99	-93.79	40.80				
36	347.3	339.9	7.40	260.6	250.1	10.5	86.7	170.9	128.2	42.7	1.91	2.02	-0.11	-52.71	-93.63	40.92				
37	351.4	344.2	7.18	264.9	254.7	10.2	86.5	172.9	130.3	42.5	1.97	2.09	-0.12	-52.40	-93.43	41.03				
38	355.5	348.5	6.97	269.3	259.4	9.9	86.2	174.9	132.5	42.4	2.04	2.16	-0.12	-52.05	-93.19	41.14				
39	359.7	353.0	6.76	273.8	264.2	9.6	86.0	177.0	134.7	42.3	2.09	2.22	-0.13	-51.67	-92.90	41.23				
40	364.1	357.6	6.55	278.4	269.1	9.3	85.7	179.2	137.0	42.2	2.16	2.28	-0.12	-51.25	-92.57	41.32				
41	368.6	362.3	6.36	283.2	274.1	9.0	85.4	181.4	139.3	42.0	2.21	2.34	-0.13	-50.80	-92.20	41.40				
42	373.0	366.8	6.17	287.8	279.1	8.7	85.2	183.5	141.6	41.9	2.16	2.29	-0.13	-50.32	-91.79	41.47				
43	377.3	371.3	5.98	292.4	283.9	8.5	84.9	185.6	143.8	41.8	2.10	2.23	-0.13	-49.81	-91.35	41.54				
44	381.4	375.6	5.80	296.8	288.5	8.2	84.7	187.7	146.0	41.7	2.05	2.17	-0.12	-49.28	-90.87	41.60				
45	385.5	379.9	5.63	301.1	293.1	8.0	84.4	189.7	148.1	41.5	2.00	2.12	-0.12	-48.72	-90.37	41.65				
46	389.4	384.0	5.46	305.3	297.5	7.7	84.2	191.6	150.2	41.4	1.94	2.06	-0.12	-48.15	-89.85	41.70				
47	393.3	388.0	5.30	309.3	301.8	7.5	84.0	193.5	152.2	41.3	1.89	2.01	-0.12	-47.56	-89.31	41.75				
48	397.0	391.9	5.14	313.3	306.0	7.3	83.7	195.3	154.1	41.2	1.84	1.95	-0.11	-46.96	-88.75	41.79				
49	400.6	395.7	4.98	317.1	310.1	7.1	83.5	197.1	156.0	41.1	1.78	1.89	-0.10	-46.35	-88.17	41.82				
50	404.2	399.3	4.83	320.9	314.0	6.9	83.3	198.9	157.9	41.0	1.73	1.84	-0.11	-45.72	-87.58	41.86				
51	407.6	402.9	4.69	324.5	317.8	6.7	83.1	200.5	159.6	40.9	1.68	1.78	-0.10	-45.08	-86.97	41.89				
52	410.9	406.4	4.55	328.0	321.6	6.5	82.9	202.2	161.4	40.8	1.63	1.73	-0.10	-44.44	-86.36	41.91				
53	414.1	409.7	4.41	331.4	325.2	6.3	82.7	203.8	163.1	40.7	1.59	1.68	-0.09	-43.79	-85.73	41.94				
54	417.3	413.0	4.28	334.8	328.7	6.1	82.5	205.3	164.7	40.6	1.54	1.64	-0.10	-43.14	-85.10	41.96				
55	420.3	416.2	4.15	338.0	332.1	5.9	82.3	206.8	166.3	40.5	1.50	1.58	-0.09	-42.48	-84.46	41.98				
56	423.3	419.2	4.03	341.1	335.4	5.7	82.1	208.2	167.8	40.4	1.45	1.54	-0.09	-41.82	-83.82	42.00				
57	426.1	422.2	3.91	344.1	338.6	5.5	82.0	209.7	169.3	40.3	1.41	1.49	-0.08	-41.16	-83.17	42.01				
58	428.9	425.1	3.79	347.1	341.7	5.4	81.8	211.0	170.8	40.2	1.36	1.45	-0.08	-40.50	-82.52	42.02				
59	431.6	427.9	3.67	349.9	344.7	5.2	81.6	212.3	172.2	40.2	1.33	1.41	-0.08	-39.83	-81.87	42.03				
60	434.2	430.6	3.56	352.7	347.7	5.1	81.5	213.6	173.5	40.1	1.29	1.36	-0.07	-39.17	-81.22	42.04				
											0.6	-42.0	42.55							

Notes A Total mass (above- , below-ground biomass, necromass) and off-site (extracted timber with provision for volatilisation at 3 % per year)
Pre-logging values includes existing necromass of 39 tC ha^{-1} (Pinard, *pers.comm.*) but the latter is excluded from post-logging values because the decay profile is not available

B. Biomass is converted to tonnes of carbon by multiplying 0.492

C. Annual flow is calculated from this year minus previous year's carbon

D. Mean Carbon storage = Sum of column (B) divided by the number of years

PTE = present tonne equivalent

Appendix 7.1 Summary statistics of rattan density, harvest yield and economic valuation

Price/cost assumptions	
Big cane	
Price	6.00
cost	2.20
net	**3.80**
Small cane	
pnce	1 10
cost	0.70
net	**0.40**

	Net profit (revenue - cost)					
NPV	RILbig	Clbig	RILsm	CLsm	RILbig+sm	Clbig+sm
0%	$1,292.00	$430 92	$653.18	$490.00	$1,945.18	$920.92
2%	$669.71	$223.37	$349 22	$261.97	$1,018.93	$485.34
4%	$389 06	$129.76	$206.12	$154.63	$595 18	$284.39
6%	$247 55	$82 56	$132.05	$99 06	$379 59	$181.62
8%	$168 52	$56.21	$90.18	$67 65	$258.71	$123.86
10%	$120.44	$40 17	$64 65	$48 50	$185.09	$88.67
12%	$89.13	$29.73	$48.07	$36 06	$137 20	$65.79

Yr	Plant density				Price/cost	RILbig		RILsm		Clbig		CLsm		Net profit (revenue - cost)			
	RILbig	Clbig	RILsm	CL	Big cane	Rev	Cost	Rev	cost	Rev	cost	Rev	cost	RILbig	CLbig	RILsm	CLsm
1	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	60.48	45.37	1	0	0	66.528	42.34	0	0	49 91	31.76	0	0	24.19	18 15
9	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	60.48	45.37	2	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
11	0	0	0	0		0	0	0	0 0	0	0	0	0	0	0	0	0
12	68	22.68	60.48	45 37	3	408	149.6	66.528	42.34	136.08	49 90	49.91	31.76	258.40	86.18	24.19	18.15
13	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	60.48	45.37	4	0	0	66.528	42.34	0	0	49 91	31 76	0	0	24.19	18.15
15	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	60.48	45 37	5	0	0	66.528	42.34	0	0	49.91	31 76	0	0	24.19	18.15
17	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	60.48	45.37	6	0	0	66 528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
19	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	60.48	45.37	7	0	0	66.528	42.34	0	0	49.91	31 76	0	0	24.19	18.15
21	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	60.48	45.37	8	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
23	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
24	68	22.68	60.48	45.37	9	408	149 6	66 528	42.34	136 08	49.90	49.91	31.76	258.40	86.18	24.19	18.15
25	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	60.48	45.37	10	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
27	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	60.48	45.37	11	0	0	66 528	42 34	0	0	49.91	31.76	0	0	24.19	18.15
29	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	60.48	45.37	12	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
31	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	60.48	45.37	13	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
33	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	60.48	45.37	14	0	0	66.528	42 34	0	0	49.91	31.76	0	0	24.19	18.15
35	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
36	68	22.68	60.48	45.37	15	408	149.6	66.528	42.34	136.08	49.90	49.91	31.76	258.40	86.18	24.19	18.15
37	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	60.48	45.37	16	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
39	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	60.48	45.37	17	0	0	66 528	42.34	0	0	49 91	31.76	0	0	24.19	18.15
41	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	60.48	45.37	18	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
43	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	60.48	45 37	19	0	0	66 528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
45	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	60.48	45.37	20	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24 19	18.15
47	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
48	68	22.68	60.48	45.37	21	408	149.6	66.528	42.34	136.08	49.90	49.91	31.76	258.40	86.18	24.19	18.15
49	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	60.48	45.37	22	0	0	66.528	42.34	0	0	49.91	31 76	0	0	24.19	18.15
51	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	60.48	45.37	23	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
53	0	0	0	0		0	0	0	0.00	0	0	0	0	0	0	0	0
54	0	0	60.48	45.37	24	0	0	66.528	42.34	0	0	49.91	31.76	0	0	24.19	18.15
55	0	0	0	0		0	0	0	0.00	0	0	0	0	0	0	0	0
56	0	0	60.48	45 37	25	0	0	66.528	42.34	0	0	49.91	31 76	0	0	24.19	18.15
57	0	0	0	0		0	0	0	0 00	0	0	0	0	0	0	0	0
58	0	0	60.48	45.37	26	0	0	66.528	42.34	0	0	49 91	31.76	0	0	24.19	18 15
59	0	0	0	0		0	0	0	0 00	0	0	0	0	0	0	0	0
60	68	22.68	60.48	45.37	27	408.00	149.60	66.53	42.34	136.08	49.90	49 91	31 76	258.40	86.18	24.19	18.15
Sum	340	113.4	1,633	1,225		2040.00	748 00	1796.26	1143 07	680.40	249.48	1347 49	857.49	1,292	431 #	653	490

Appendix 8.1 Projected sediment yield data and economic costs of sedimentation over 60 years

Yea	Sediment yield (m^3)			Hours to dredge			Dredging cost (RM/yr)			Hydroelectricity cost		
	RIL_H	RIL_L	CL	RIL_H	RIL_L	CL	RIL_H	RIL_L	CL	RIL_H	RIL_L	CL
1	37.44	30.09	109.15	0.208	0.167	0.606	41.56	33.40	121.15	1325.77	1065.40	3864.77
2	37.19	29.89	108.83	0.206	0.166	0.604	41.28	33.18	120.81	1316.93	1058.30	3853.72
3	36.94	29.69	108.52	0.205	0.165	0.602	41 01	32.95	120.46	1308.09	1051.20	3842.68
4	36.69	29.49	108.21	0.204	0.164	0.601	40.73	32.73	120.11	1299.25	1044 09	3831.64
5	36.44	29.29	107.90	0.202	0.163	0.599	40.45	32.51	119.77	1290.41	1036.99	3820.60
6	36.19	29.09	107.59	0.201	0.161	0.597	40.17	32.28	119.42	1281.57	1029.89	3809.56
7	35.94	28.88	107.28	0.199	0.160	0.595	39.90	32.06	119.08	1272.73	1022.79	3798.51
8	35.69	28.68	106.96	0.198	0.159	0.594	39.62	31.84	118.73	1263.90	1015.68	3787.47
9	35.44	28.48	106.65	0.197	0.158	0.592	39.34	31.62	118.38	1255.06	1008.58	3776.43
10	35.19	28.28	106.34	0.195	0.157	0.590	39.07	31.39	118.04	1246.22	1001.48	3765 39
11	34.95	28.08	106.03	0.194	0.156	0.588	38.79	31.17	117.69	1237.38	994.38	3754.34
12	34.70	27.88	105.72	0.193	0.155	0.587	38.51	30.95	117.34	1228.54	987.27	3743.30
13	34.45	27.68	105.40	0.191	0.154	0.585	38.24	30.73	117 00	1219.70	980.17	3732.26
14	34.20	27.48	105.09	0.190	0.153	0.583	37.96	30.50	116.65	1210.87	973.07	3721.22
15	33.95	27.28	104.78	0.188	0.151	0.582	37.68	30.28	116.31	1202.03	965.97	3710.18
16	33.70	27.08	104.47	0.187	0.150	0.580	37.40	30.06	115.96	1193.19	958.86	3699.13
17	33.45	26.88	104.16	0.186	0.149	0.578	37.13	29.84	115.61	1184.35	951.76	3688.09
18	33.20	26.68	103.85	0.184	0.148	0.576	36.85	29.61	115.27	1175.51	944.66	3677.05
19	32.95	26.48	103.53	0.183	0.147	0.575	36.57	29.39	114.92	1166.67	937.55	3666.01
20	32.70	26.28	103.22	0.181	0.146	0.573	36.30	29.17	114.58	1157.83	930.45	3654.97
21	32.45	26.08	102.91	0.180	0.145	0.571	36.02	28.95	114.23	1149.00	923.35	3643.92
22	32.20	25.88	102.60	0.179	0.144	0.569	35.74	28.72	113.88	1140.16	916.25	3632.88
23	31.95	25.68	102.29	0.177	0.142	0.568	35.46	28.50	113.54	1131.32	909.14	3621.84
24	31.70	25.47	101.97	0.176	0.141	0.566	35.19	28.28	113.19	1122.48	902.04	3610.80
25	31.45	25.27	101.66	0.175	0.140	0.564	34.91	28.05	112.84	1113.64	894.94	3599.75
26	31.20	25.07	101.35	0.173	0.139	0.562	34.63	27.83	112.50	1104.80	887.84	3588.71
27	30.95	24.87	101.04	0.172	0.138	0.561	34.36	27.61	112.15	1095.97	880.73	3577.67
28	30.70	24.67	100.73	0.170	0.137	0.559	34.08	27.39	111.81	1087.13	873.63	3566.63
29	30.45	24.47	100.41	0.169	0.136	0.557	33.80	27.16	111.46	1078.29	866.53	3555.59
30	30.20	24.27	100.10	0.168	0.135	0.556	33.53	26.94	111.11	1069.45	859.42	3544.54
31	29.95	24.07	99.79	0.166	0.134	0.554	33.25	26.72	110.77	1060.61	852.32	3533.50
32	29.70	23.87	99.48	0.165	0.132	0.552	32.97	26.50	110.42	1051.77	845.22	3522.46
33	29.45	23.67	99.17	0.163	0.131	0.550	32.69	26.27	110.08	1042.94	838.12	3511.42
34	29.20	23.47	98.86	0.162	0.130	0.549	32.42	26.05	109.73	1034.10	831.01	3500.37
35	28.95	23.27	98.54	0.161	0.129	0.547	32.14	25.83	109.38	1025.26	823.91	3489.33
36	28.71	23.07	98.23	0.159	0.128	0.545	31.86	25.61	109.04	1016.42	816.81	3478.29
37	28.46	22.87	97.92	0.158	0.127	0.543	31.59	25.38	108.69	1007.58	809.71	3467.25
38	28.21	22.67	97.61	0.157	0.126	0.542	31.31	25.16	108.35	998.74	802.60	3456.21
39	27.96	22.47	97.30	0.155	0.125	0.540	31.03	24.94	108.00	989.90	795.50	3445.16
40	27.71	22.27	96.98	0.154	0.124	0.538	30.75	24.71	107.65	981.07	788.40	3434.12
41	27.46	22.06	96.67	0.152	0.122	0.537	30.48	24.49	107.31	972.23	781.30	3423.08
42	27.21	21.86	96.36	0.151	0.121	0.535	30.20	24.27	106.96	963.39	774.19	3412.04
43	26.96	21.66	96.05	0.150	0.120	0.533	29.92	24.05	106.61	954.55	767.09	3400.99
44	26.71	21.46	95.74	0.148	0.119	0.531	29.65	23.82	106.27	945.71	759.99	3389.95
45	26.46	21.26	95.43	0.147	0.118	0.530	29.37	23.60	105.92	936.87	752.88	3378.91
46	26.21	21.06	95.11	0.145	0.117	0.528	29.09	23.38	105.58	928.04	745.78	3367.87
47	25.96	20.86	94.80	0.144	0.116	0.526	28.81	23.16	105.23	919.20	738.68	3356.83
48	25.71	20.66	94.49	0.143	0.115	0.524	28.54	22.93	104.88	910.36	731.58	3345.78
49	25.46	20.46	94.18	0.141	0.114	0.523	28.26	22.71	104.54	901.52	724.47	3334.74
50	25.21	20.26	93.87	0.140	0.112	0.521	27.98	22.49	104.19	892.68	717.37	3323.70
51	24.96	20.06	93.55	0.139	0.111	0.519	27.71	22.27	103.85	883.84	710.27	3312.66
52	24.71	19.86	93.24	0.137	0.110	0.517	27.43	22.04	103.50	875.01	703.17	3301.61
53	24.46	19.66	92.93	0.136	0.109	0.516	27.15	21.82	103.15	866.17	696.06	3290.57
54	24.21	19.46	92.62	0.134	0.108	0.514	26.88	21.60	102.81	857.33	688.96	3279.53
55	23.96	19.26	92.31	0.133	0.107	0.512	26.60	21.37	102.46	848.49	681.86	3268.49
56	23.71	19.06	91.99	0.132	0.106	0.511	26.32	21.15	102.11	839.65	674.76	3257.45
57	23.46	18.86	91.68	0.130	0.105	0.509	26.04	20.93	101.77	830.81	667.65	3246.40
58	23.21	18.65	91.37	0.129	0.104	0.507	25.77	20.71	101.42	821.97	660.55	3235.36
59	22.96	18.45	91.06	0.127	0.102	0.505	25.49	20.48	101.08	813.14	653.45	3224.32
60	22.71	18.25	90.75	0.126	0.101	0.504	25.21	20.26	100.73	804.30	646.34	3213.28
	1805	1450	5997	10.016	8.049	33.282	2003.19	1609.79	6656.47	63901.88	51352.42	212341.32

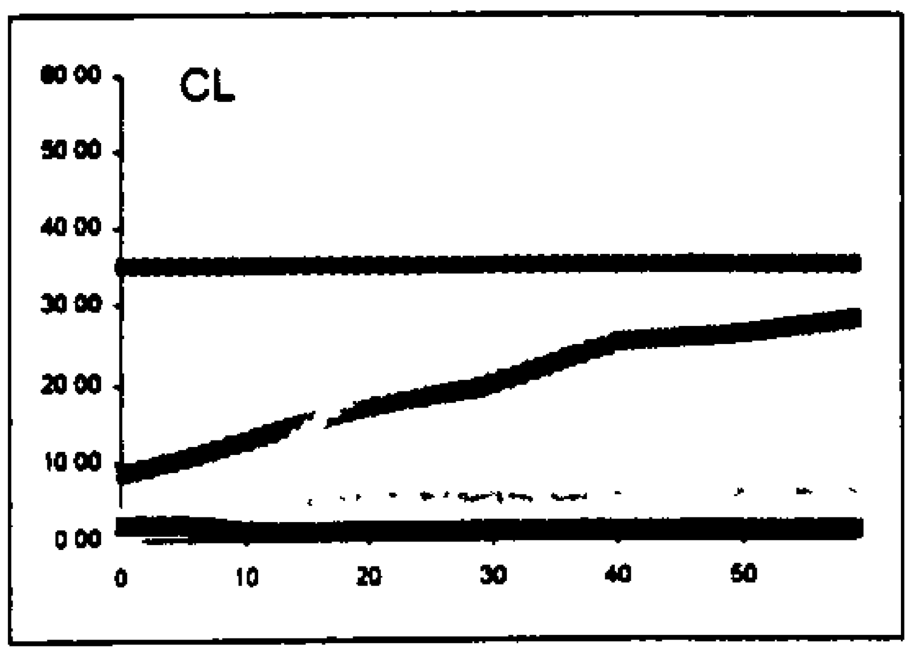
Appendix 9.1 Projected animal density, harvest yields, and economic valuation of wildlife in the study area

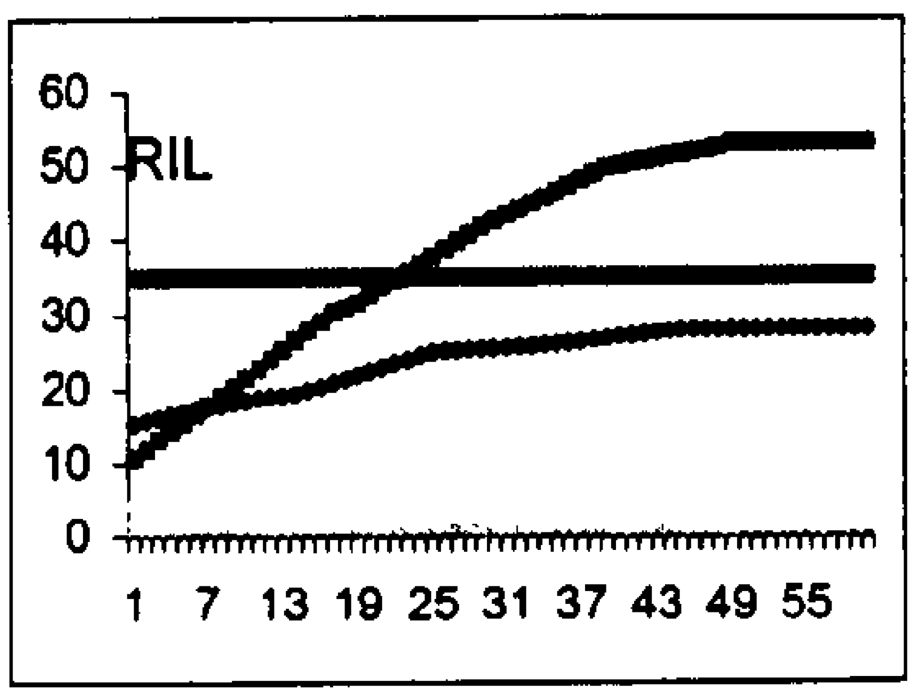
Assumptions of animal carcass

weight, price and harvesting cost

Valuation	wt	Net revenue (RM)	
java	2 4	2	Net revenue = Price-cost
napu	4 2	2	N.B. Cost at 50 % of price
mun	13	2	
deer	50	3	
pig	30	2 5	

Area	
RIL	100 ha
CL	100 ha





No hunting - CL						No hunting - RIL				
						T java	T napu	M spp	Deer	
0	javacl	napu	mun	Deer	Pig	MD1	MD2	BD	SD	pig
1	8 57	0 35	3.46	2	35	15 38	10.84	5.05	1 00	35
2	8 95	0 93	3 60	2	35	15 79	11 98	5.11	1 00	35
3	9 34	1 58	3 74	2	35	16.19	13 13	5 15	1 00	35
4	9 75	2 28	3 86	2	35	16 58	14 31	5 19	1 00	35
5	10 16	3.05	3 99	2	35	16 95	15 50	5 23	1 00	35
6	10 58	3 87	4 10	2	35	17 31	16 71	5.26	1 00	35
7	11 01	4 74	4 22	1 85	35	17 65	17.94	5 28	1 00	35
8	11 45	5 66	4 33	2	35	17 98	19 18	5.30	1 00	35
9	11 89	6 62	4 43	1 55	35	18 28	20.42	5 31	1 00	35
10	12 33	7 63	4 52	1	35	18 56	21 67	5 31	1 00	35
11	12 77	8 67	4 62	1.25	35	18 81	22 92	5 31	1 00	35
12	13 21	9 74	4 70	1	35	19 04	24 18	5.30	1.00	35
13	13 65	10 84	4.78	1	35	19 24	25 43	5 29	1 00	35
14	14 09	11 98	4 86	1	35	19 42	26 69	5 27	1 00	35
15	14 53	13 13	4 93	1	35	20 00	27 93	5.24	1 00	35
16	14 96	14 31	4 99	1	35	20 50	29 18	5 05	1 00	35
17	15 38	15 50	5 05	1	35	21 00	30.41	5 11	1 00	35
18	15.79	16 71	5 11	1	35	21 50	31 00	5 15	1.00	35
19	16.19	17 94	5 15	1	35	22.00	31 70	5 19	1 00	35
20	16.58	19.18	5 19	1	35	22 50	32 70	5.23	1 00	35
21	16 95	20.42	5 23	1	35	23.00	33 70	5 42	1.00	35
22	17.31	21 67	5 26	1	35	23.50	34 70	5 61	1 00	35
23	17 65	22 92	5 28	1	35	24 00	35.70	5 80	1 00	35
24	17 98	24 18	5 30	1	35	24.50	36 70	5 99	1.00	35
25	18 28	25.43	5 31	1	35	25 00	37 70	6 00	1 00	35
26	18 56	26.69	5 31	1	35	25.10	38.70	6 00	1.00	35
27	18 81	27 93	5 31	1	35	25 20	39 70	6 00	1 00	35
28	19.04	29.18	5 30	1	35	25.30	40.70	6.00	1.00	35
29	19.24	30.41	5 29	1	35	25 40	41 70	6.00	1.00	35
30	19 42	31 00	5 27	1	35	25 50	42 50	6 00	1 00	35
31	20 00	31 70	5 24	1	35	25 60	43 30	6.00	1 00	35
32	20 50	32.70	5 21	1	35	25 70	44 10	6 00	1 00	35
33	21 00	33.70	5.17	1	35	25 80	44 90	6 00	1 00	35
34	21 50	34 70	5 12	1	35	25 90	45 70	6.00	1 00	35
35	22.00	35.70	5.06	1	35	26.00	46 50	6.00	1.00	35
36	22.50	36 70	5 20	1	35	26.20	47.30	6 00	1.00	35
37	23 00	37.70	5.34	1	35	26.40	48 10	6 00	1.00	35
38	23 50	38.70	5 47	1	35	26 60	48 90	6.00	1.00	35
39	24.00	39 70	5 61	1	35	26.80	49 70	6 00	1 00	35
40	24.50	40.70	6.00	1	35	27 00	50 00	6 00	1 00	35
41	25.00	41 70	6.00	1	35	27 20	50 30	6.00	1.00	35
42	25 10	42 50	6.00	1	35	27 40	50 60	6 00	1 00	35
43	25 20	43 30	6 00	1	35	27 60	50.90	6.00	1 00	35
44	25 30	44 10	6.00	1	35	27.80	51 20	6 00	1.00	35
45	25 40	44 90	6 00	1	35	28 00	51.50	6 00	1 00	35
46	25 50	45 70	6 00	1	35	28 00	51.80	6 00	1.00	35
47	25.60	46.50	6.00	1	35	28.00	52 10	6 00	1.00	35
48	25.70	47 30	6 00	1	35	28.00	52.40	6 00	1 00	35
49	25 80	48 10	6 00	1	35	28 00	53.00	6.00	1.00	35
50	25 90	48.90	6 00	1	35	28.00	53 00	6.00	1.00	35
51	26 00	49 70	6 00	1	35	28 00	53.00	6.00	1.00	35
52	26.20	50 00	6 00	1	35	28.00	53 00	6 00	1.00	35
53	26 40	50 30	6 00	1	35	28 00	53.00	6 00	1.00	35
54	26 60	50 60	6 00	1	35	28.00	53 00	6 00	1 00	35
55	26 80	50 90	6 00	1	35	28 00	53 00	6 00	1 00	35
56	27 00	51 20	6 00	1	35	28.00	53 00	6 00	1 00	35
57	27 20	51.50	6 00	1	35	28.00	53.00	6 00	1 00	35
58	27 40	51 80	6 00	1	35	28 00	53.00	6.00	1 00	35
59	27 60	52.10	6 00	1	35	28 00	53 00	6 00	1 00	35
60	27 80	52.40	6 00	1	35	28 00	53 00	6.00	1 00	35
Total	1180	1760	316	74	2100	1441	2341	343	60	2100
p/ha	11 80	17 60	3 16	0 74	21 00	14 41	23 41	3 43	0.60	21.00
Mean	19 67	29.33	5 27	1 23	35 00	24 02	39.02	5.72	1 00	35 00
p/ha	0 20	0 29	0 05	0.01	0 35	0 24	0 39	0 06	0 01	0 35

cull@	0.1 per year for CL				cull@	0.1 per year for RIL				cull@	0.4 per year for CL				cull@	0.4 per year for RIL			
T java	T napı	M spp	Deer		T java	T napı	M spp	Deer		T java	T napu	M spı	Deer		T java	T napu	M spp	Deer	
MD1	MD2	BD	SD	Pig	MD1	MD2	BD	SD	Pig	MD1	MD2	BD	SD	Pig	MD1	MD2	BD	SD	Pig
0.86	0.04	0.35	0.20	3.50	1.54	1.08	0.51	0.10	3.50	3.43	0.14	1.39	0.80	14	6.15	4.34	2.02	0.40	14
0.89	0.09	0.36	0.20	3.50	1.58	1.20	0.51	0.10	3.50	3.58	0.37	1.44	0.80	14	6.32	4.79	2.04	0.40	14
0.93	0.16	0.37	0.20	3.50	1.62	1.31	0.52	0.10	3.50	3.74	0.63	1.49	0.80	14	6.48	5.25	2.06	0.40	14
0.97	0.23	0.39	0.20	3.50	1.66	1.43	0.52	0.10	3.50	3.90	0.91	1.55	0.80	14	6.63	5.72	2.08	0.40	14
1.02	0.30	0.40	0.20	3.50	1.70	1.55	0.52	0.10	3.50	4.06	1.22	1.59	0.80	14	6.78	6.20	2.09	0.40	14
1.06	0.39	0.41	0.20	3.50	1.73	1.67	0.53	0.10	3.50	4.23	1.55	1.64	0.80	14	6.92	6.69	2.10	0.40	14
1.10	0.47	0.42	0.19	3.50	1.77	1.79	0.53	0.10	3.50	4.40	1.90	1.69	0.74	14	7.06	7.18	2.11	0.40	14
1.14	0.57	0.43	0.17	3.50	1.80	1.92	0.53	0.10	3.50	4.58	2.26	1.73	0.68	14	7.19	7.67	2.12	0.40	14
1.19	0.66	0.44	0.16	3.50	1.83	2.04	0.53	0.10	3.50	4.75	2.65	1.77	0.62	14	7.31	8.17	2.12	0.40	14
1.23	0.76	0.45	0.14	3.50	1.86	2.17	0.53	0.10	3.50	4.93	3.05	1.81	0.56	14	7.42	8.67	2.13	0.40	14
1.28	0.87	0.46	0.13	3.50	1.88	2.29	0.53	0.10	3.50	5.11	3.47	1.85	0.50	14	7.53	9.17	2.12	0.40	14
1.32	0.97	0.47	0.11	3.50	1.90	2.42	0.53	0.10	3.50	5.29	3.90	1.88	0.44	14	7.62	9.67	2.12	0.40	14
1.37	1.08	0.48	0.11	3.50	1.92	2.54	0.53	0.10	3.50	5.46	4.34	1.91	0.44	14	7.70	10.17	2.12	0.40	14
1.41	1.20	0.49	0.11	3.50	1.94	2.67	0.53	0.10	3.50	5.64	4.79	1.94	0.44	14	7.77	10.67	2.11	0.40	14
1.45	1.31	0.49	0.11	3.50	2.00	2.79	0.52	0.10	3.50	5.81	5.25	1.97	0.44	14	8.00	11.17	2.10	0.40	14
1.50	1.43	0.50	0.11	3.50	2.05	2.92	0.51	0.10	3.50	5.98	5.72	2.00	0.44	14	8.20	11.67	2.02	0.40	14
1.54	1.55	0.51	0.11	3.50	2.10	3.04	0.51	0.10	3.50	6.15	6.20	2.02	0.44	14	8.40	12.16	2.04	0.40	14
1.58	1.67	0.51	0.11	3.50	2.15	3.10	0.52	0.10	3.50	6.32	6.69	2.04	0.44	14	8.60	12.40	2.06	0.40	14
1.62	1.79	0.52	0.11	3.50	2.20	3.17	0.52	0.10	3.50	6.48	7.18	2.06	0.44	14	8.80	12.68	2.08	0.40	14
1.66	1.92	0.52	0.11	3.50	2.25	3.27	0.52	0.10	3.50	6.63	7.67	2.08	0.44	14	9.00	13.08	2.09	0.40	14
1.70	2.04	0.52	0.11	3.50	2.30	3.37	0.54	0.10	3.50	6.78	8.17	2.09	0.44	14	9.20	13.48	2.17	0.40	14
1.73	2.17	0.53	0.11	3.50	2.35	3.47	0.56	0.10	3.50	6.92	8.67	2.10	0.44	14	9.40	13.88	2.24	0.40	14
1.77	2.29	0.53	0.11	3.50	2.40	3.57	0.58	0.10	3.50	7.06	9.17	2.11	0.44	14	9.60	14.28	2.32	0.40	14
1.80	2.42	0.53	0.11	3.50	2.45	3.67	0.60	0.10	3.50	7.19	9.67	2.12	0.44	14	9.80	14.68	2.40	0.40	14
1.83	2.54	0.53	0.11	3.50	2.50	3.77	0.60	0.10	3.50	7.31	10.17	2.12	0.44	14	10.00	15.08	2.40	0.40	14
1.86	2.67	0.53	0.11	3.50	2.51	3.87	0.60	0.10	3.50	7.42	10.67	2.13	0.44	14	10.04	15.48	2.40	0.40	14
1.88	2.79	0.53	0.11	3.50	2.52	3.97	0.60	0.10	3.50	7.53	11.17	2.12	0.44	14	10.08	15.88	2.40	0.40	14
1.90	2.92	0.53	0.11	3.50	2.53	4.07	0.60	0.10	3.50	7.62	11.67	2.12	0.44	14	10.12	16.28	2.40	0.40	14
1.92	3.04	0.53	0.11	3.50	2.54	4.17	0.60	0.10	3.50	7.70	12.16	2.12	0.44	14	10.16	16.68	2.40	0.40	14
1.94	3.10	0.53	0.11	3.50	2.55	4.25	0.60	0.10	3.50	7.77	12.40	2.11	0.44	14	10.20	17.00	2.40	0.40	14
2.00	3.17	0.52	0.11	3.50	2.56	4.33	0.60	0.10	3.50	8.00	12.68	2.10	0.44	14	10.24	17.32	2.40	0.40	14
2.05	3.27	0.52	0.11	3.50	2.57	4.41	0.60	0.10	3.50	8.20	13.08	2.08	0.44	14	10.28	17.64	2.40	0.40	14
2.10	3.37	0.52	0.11	3.50	2.58	4.49	0.60	0.10	3.50	8.40	13.48	2.07	0.44	14	10.32	17.96	2.40	0.40	14
2.15	3.47	0.51	0.11	3.50	2.59	4.57	0.60	0.10	3.50	8.60	13.88	2.05	0.44	14	10.36	18.28	2.40	0.40	14
2.20	3.57	0.51	0.11	3.50	2.60	4.65	0.60	0.10	3.50	8.80	14.28	2.03	0.44	14	10.40	18.60	2.40	0.40	14
2.25	3.67	0.52	0.11	3.50	2.62	4.73	0.60	0.10	3.50	9.00	14.68	2.08	0.44	14	10.48	18.92	2.40	0.40	14
2.30	3.77	0.53	0.11	3.50	2.64	4.81	0.60	0.10	3.50	9.20	15.08	2.13	0.44	14	10.56	19.24	2.40	0.40	14
2.35	3.87	0.55	0.11	3.50	2.66	4.89	0.60	0.10	3.50	9.40	15.48	2.19	0.44	14	10.64	19.56	2.40	0.40	14
2.40	3.97	0.56	0.11	3.50	2.68	4.97	0.60	0.10	3.50	9.60	15.88	2.24	0.44	14	10.72	19.88	2.40	0.40	14
2.45	4.07	0.60	0.11	3.50	2.70	5.00	0.60	0.10	3.50	9.80	16.28	2.40	0.44	14	10.80	20.00	2.40	0.40	14
2.50	4.17	0.60	0.11	3.50	2.72	5.03	0.60	0.10	3.50	10.00	16.68	2.40	0.44	14	10.88	20.12	2.40	0.40	14
2.51	4.25	0.60	0.11	3.50	2.74	5.06	0.60	0.10	3.50	10.04	17.00	2.40	0.44	14	10.96	20.24	2.40	0.40	14
2.52	4.33	0.60	0.11	3.50	2.76	5.09	0.60	0.10	3.50	10.08	17.32	2.40	0.44	14	11.04	20.36	2.40	0.40	14
2.53	4.41	0.60	0.11	3.50	2.78	5.12	0.60	0.10	3.50	10.12	17.64	2.40	0.44	14	11.12	20.48	2.40	0.40	14
2.54	4.49	0.60	0.11	3.50	2.80	5.15	0.60	0.10	3.50	10.16	17.96	2.40	0.44	14	11.20	20.60	2.40	0.40	14
2.55	4.57	0.60	0.11	3.50	2.80	5.18	0.60	0.10	3.50	10.20	18.28	2.40	0.44	14	11.20	20.72	2.40	0.40	14
2.56	4.65	0.60	0.11	3.50	2.80	5.21	0.60	0.10	3.50	10.24	18.60	2.40	0.44	14	11.20	20.84	2.40	0.40	14
2.57	4.73	0.60	0.11	3.50	2.80	5.24	0.60	0.10	3.50	10.28	18.92	2.40	0.44	14	11.20	20.96	2.40	0.40	14
2.58	4.81	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.32	19.24	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.59	4.89	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.36	19.56	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.60	4.97	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.40	19.88	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.62	5.00	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.48	20.00	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.64	5.03	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.56	20.12	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.66	5.06	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.64	20.24	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.68	5.09	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.72	20.36	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.70	5.12	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.80	20.48	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.72	5.15	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.88	20.60	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.74	5.18	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	10.96	20.72	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.76	5.21	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	11.04	20.84	2.40	0.44	14	11.20	21.20	2.40	0.40	14
2.78	5.24	0.60	0.11	3.50	2.80	5.30	0.60	0.10	3.50	11.12	20.96	2.40	0.44	14	11.20	21.20	2.40	0.40	14
118	176	32	7	210	144	234	34	6	210	472	704	126	29	840	576	936	137	24	840
1.18	1.76	0.32	0.07	2.10	1.44	2.34	0.34	0.06	2.10	4.72	7.04	1.26	0.29	8.40	5.76	9.36	1.37	0.24	8.40
1.97	2.93	0.53	0.12	3.50	2.40	3.90	0.57	0.10	3.50	7.87	11.73	2.11	0.49	14	9.61	15.61	2.29	0.40	14.0
0.02	0.03	0.01	0.00	0.04	0.02	0.04	0.01	0.00	0.04	0.08	0.12	0.02	0.00	0.14	0.10	0.16	0.02	0.00	0.14

Value at 10 % culling for CL						Value at 10 % culling for RIL					
T java	T.napu	M spp	Deer			T java	T.napu	M.spp.	Deer		
MD1	MD2	BD	SD	Pig	sum	MD1	MD2	BD	SD	Pig	sum
4.11	0.30	9.01	30.00	262.50	305.92	7.38	9.11	13.14	15.00	262.50	307.13
4.30	0.78	9.37	30.00	262.50	306.94	7.58	10.06	13.27	15.00	262.50	308.41
4.48	1.32	9.71	30.00	262.50	308.02	7.77	11.03	13.40	15.00	262.50	309.70
4.68	1.92	10.05	30.00	262.50	309.14	7.96	12.02	13.50	15.00	262.50	310.98
4.88	2.56	10.37	30.00	262.50	310.30	8.14	13.02	13.59	15.00	262.50	312.26
5.08	3.25	10.67	30.00	262.50	311.50	8.31	14.04	13.67	15.00	262.50	313.52
5.29	3.98	10.97	27.75	262.50	310.48	8.47	15.07	13.73	15.00	262.50	314.77
5.49	4.75	11.25	25.50	262.50	309.49	8.63	16.11	13.78	15.00	262.50	316.01
5.70	5.56	11.51	23.25	262.50	308.53	8.77	17.15	13.80	15.00	262.50	317.23
5.92	6.41	11.76	21.00	262.50	307.59	8.91	18.20	13.82	15.00	262.50	318.43
6.13	7.28	12.00	18.75	262.50	306.66	9.03	19.26	13.81	15.00	262.50	319.60
6.34	8.18	12.23	16.50	262.50	305.75	9.14	20.31	13.79	15.00	262.50	320.74
6.55	9.11	12.44	16.50	262.50	307.10	9.24	21.36	13.75	15.00	262.50	321.85
6.76	10.06	12.64	16.50	262.50	308.46	9.32	22.42	13.70	15.00	262.50	322.93
6.97	11.03	12.82	16.50	262.50	309.82	9.60	23.46	13.63	15.00	262.50	324.19
7.18	12.02	12.98	16.50	262.50	311.18	9.84	24.51	13.14	15.00	262.50	324.99
7.38	13.02	13.14	16.50	262.50	312.54	10.08	25.55	13.27	15.00	262.50	326.40
7.58	14.04	13.27	16.50	262.50	313.89	10.32	26.04	13.40	15.00	262.50	327.26
7.77	15.07	13.40	16.50	262.50	315.24	10.56	26.63	13.50	15.00	262.50	328.19
7.96	16.11	13.50	16.50	262.50	316.57	10.80	27.47	13.59	15.00	262.50	329.36
8.14	17.15	13.59	16.50	262.50	317.88	11.04	28.31	14.09	15.00	262.50	330.94
8.31	18.20	13.67	16.50	262.50	319.18	11.28	29.15	14.59	15.00	262.50	332.52
8.47	19.26	13.73	16.50	262.50	320.46	11.52	29.99	15.09	15.00	262.50	334.09
8.63	20.31	13.78	16.50	262.50	321.71	11.76	30.83	15.58	15.00	262.50	335.67
8.77	21.36	13.80	16.50	262.50	322.94	12.00	31.67	15.60	15.00	262.50	336.77
8.91	22.42	13.82	16.50	262.50	324.14	12.05	32.51	15.60	15.00	262.50	337.66
9.03	23.46	13.81	16.50	262.50	325.31	12.10	33.35	15.60	15.00	262.50	338.54
9.14	24.51	13.79	16.50	262.50	326.44	12.14	34.19	15.60	15.00	262.50	339.43
9.24	25.55	13.75	16.50	262.50	327.54	12.19	35.03	15.60	15.00	262.50	340.32
9.32	26.04	13.70	16.50	262.50	328.06	12.24	35.70	15.60	15.00	262.50	341.04
9.60	26.63	13.63	16.50	262.50	328.85	12.29	36.37	15.60	15.00	262.50	341.76
9.84	27.47	13.54	16.50	262.50	329.85	12.34	37.04	15.60	15.00	262.50	342.48
10.08	28.31	13.43	16.50	262.50	330.82	12.38	37.72	15.60	15.00	262.50	343.20
10.32	29.15	13.31	16.50	262.50	331.78	12.43	38.39	15.60	15.00	262.50	343.92
10.56	29.99	13.17	16.50	262.50	332.71	12.48	39.06	15.60	15.00	262.50	344.64
10.80	30.83	13.52	16.50	262.50	334.15	12.58	39.73	15.60	15.00	262.50	345.41
11.04	31.67	13.87	16.50	262.50	335.58	12.67	40.40	15.60	15.00	262.50	346.18
11.28	32.51	14.23	16.50	262.50	337.01	12.77	41.08	15.60	15.00	262.50	346.94
11.52	33.35	14.58	16.50	262.50	338.45	12.86	41.75	15.60	15.00	262.50	347.71
11.76	34.19	15.60	16.50	262.50	340.55	12.96	42.00	15.60	15.00	262.50	348.06
12.00	35.03	15.60	16.50	262.50	341.63	13.06	42.25	15.60	15.00	262.50	348.41
12.05	35.70	15.60	16.50	262.50	342.35	13.15	42.50	15.60	15.00	262.50	348.76
12.10	36.37	15.60	16.50	262.50	343.07	13.25	42.76	15.60	15.00	262.50	349.10
12.14	37.04	15.60	16.50	262.50	343.79	13.34	43.01	15.60	15.00	262.50	349.45
12.19	37.72	15.60	16.50	262.50	344.51	13.44	43.26	15.60	15.00	262.50	349.80
12.24	38.39	15.60	16.50	262.50	345.23	13.44	43.51	15.60	15.00	262.50	350.05
12.29	39.06	15.60	16.50	262.50	345.95	13.44	43.76	15.60	15.00	262.50	350.30
12.34	39.73	15.60	16.50	262.50	346.67	13.44	44.02	15.60	15.00	262.50	350.56
12.38	40.40	15.60	16.50	262.50	347.39	13.44	44.52	15.60	15.00	262.50	351.06
12.43	41.08	15.60	16.50	262.50	348.11	13.44	44.52	15.60	15.00	262.50	351.06
12.48	41.75	15.60	16.50	262.50	348.83	13.44	44.52	15.60	15.00	262.50	351.06
12.58	42.00	15.60	16.50	262.50	349.18	13.44	44.52	15.60	15.00	262.50	351.06
12.67	42.25	15.60	16.50	262.50	349.52	13.44	44.52	15.60	15.00	262.50	351.06
12.77	42.50	15.60	16.50	262.50	349.87	13.44	44.52	15.60	15.00	262.50	351.06
12.86	42.76	15.60	16.50	262.50	350.22	13.44	44.52	15.60	15.00	262.50	351.06
12.96	43.01	15.60	16.50	262.50	350.57	13.44	44.52	15.60	15.00	262.50	351.06
13.06	43.26	15.60	16.50	262.50	350.92	13.44	44.52	15.60	15.00	262.50	351.06
13.15	43.51	15.60	16.50	262.50	351.26	13.44	44.52	15.60	15.00	262.50	351.06
13.25	43.76	15.60	16.50	262.50	351.61	13.44	44.52	15.60	15.00	262.50	351.06
13.34	44.02	15.60	16.50	262.50	351.96	13.44	44.52	15.60	15.00	262.50	351.06
567	1478	821	1105	15750	19721	692	1966	892	900	15750	20200
5.67	14.78	8.21	11.05	157.50	197.21	6.92	19.66	8.92	9.00	157.50	202.00
9.44	24.64	13.69	18.41	262.50	328.69	11.53	32.77	14.87	15.00	262.50	336.67
0.09	0.25	0.14	0.18	2.63	3.29	0.12	0.33	0.15	0.15	2.63	3.37

Value at 40 % culling for CL

T java	T napu	M spp	Deer		
MD1	MD2	BD	SD	Pig	sum
16 45	1 19	36 03	120.00	1050 00	1223 67
17.18	3 13	37.47	120 00	1050 00	1227 78
17 94	*5 30*	*38.85*	*120 00*	1050 00	1232.08
18 71	7 67	40 18	120 00	1050.00	1236 57
19 51	10.25	41 46	120 00	1050.00	1241.21
20 32	13 00	42 69	120 00	1050 00	1246 01
21 14	15 93	43 86	111 00	1050 00	1241 94
21 98	19 02	44 98	102.00	1050.00	1237 98
22 82	22 25	46.05	93 00	1050.00	1234 12
23 67	25 62	47 06	84 00	1050 00	1230.35
24 52	29.12	48.01	75 00	1050.00	1226 65
25 37	32 73	48 91	66 00	1050 00	1223 01
26 22	36.44	49 76	66 00	1050 00	1228 41
27.06	40 24	50 54	66 00	1050 00	1233 84
27 89	44 12	51.27	66.00	1050.00	1239.28
28.71	48.07	51.94	66 00	1050 00	1244 73
29 52	52 09	52.55	66 00	1050 00	1250.16
30.31	56 16	53 10	66 00	1050.00	1255 57
31.08	60.28	53 59	66.00	1050.00	1260.95
31.83	64 43	54 01	66 00	1050.00	1266.27
32.55	68 61	54.38	66.00	1050.00	1271 54
33 24	72.81	54.68	66.00	1050.00	1276 73
33 90	77 02	54.92	66.00	1050 00	1281 84
34 52	81.24	55.10	66.00	1050 00	1286.85
35.10	85.46	55 21	66 00	1050.00	1291.76
35 63	89 66	55 26	66 00	1050.00	1296.56
36.12	93 86	55 24	66.00	1050 00	1301 22
36.56	98 03	55.16	66 00	1050 00	1305 76
36 95	102 18	55 01	66 00	1050.00	1310.14
37.28	104 16	54.79	66 00	1050.00	1312.23
38.40	106.51	54.50	66.00	1050.00	1315 42
39.36	109.87	54 15	66.00	1050.00	1319 38
40.32	113 23	53 73	66.00	1050.00	1323.28
41 28	116.59	53.23	66 00	1050.00	1327.10
42.24	119 95	52 67	66.00	1050 00	1330 86
43.20	123 31	54.08	66 00	1050.00	1336.59
44 16	126 67	55.49	66 00	1050 00	1342.32
45.12	130 03	56 91	66 00	1050 00	1348 06
46.08	133 39	58 32	66 00	1050 00	1353 79
47 04	136.75	62 40	66.00	1050.00	1362.19
48.00	140.11	62.40	66 00	1050.00	1366.51
48.19	142.80	62 40	66.00	1050.00	1369.39
48.38	145 49	62.40	66 00	1050 00	1372 27
48.58	148 18	62.40	66.00	1050.00	1375 15
48.77	150.86	62.40	66.00	1050 00	1378 03
48.96	153.55	62.40	66 00	1050.00	1380 91
49.15	156 24	62 40	66.00	1050.00	1383.79
49.34	158.93	62.40	66.00	1050.00	1386.67
49 54	161.62	62 40	66 00	1050.00	1389.55
49 73	164 30	62 40	66.00	1050.00	1392 43
49 92	166 99	62 40	66 00	1050 00	1395.31
50 30	168 00	62 40	66.00	1050 00	1396 70
50.69	169 01	62.40	66 00	1050 00	1398.10
51.07	170.02	62.40	66 00	1050 00	1399 49
51 46	171 02	62.40	66 00	1050 00	1400 88
51 84	172 03	62.40	66 00	1050 00	1402 27
52 22	173 04	62.40	66.00	1050.00	1403 66
52 61	174.05	62 40	66 00	1050.00	1405 06
52.99	175.06	62.40	66 00	1050 00	1406 45
53 38	176 06	62 40	66 00	1050 00	1407 84
2266	5914	3286	4419	63000	78885
22.66	59.14	32.86	44.19	630 00	788 85
37.77	98 56	54 76	73.65	1050 00	1314.74
0 38	0 99	0 55	0 74	10 50	13 15

Value at 40 % culling for RIL

T java	T napu	M spp.	Deer		
MD1	MD2	BD	SD	Pig	sum
29 52	36 44	52 55	60.00	1050 00	1228 51
30 31	40 24	53 10	60 00	1050 00	1233 65
31 08	44.12	53.59	60 00	1050.00	1238 79
31.83	*48 07*	*54 01*	*60 00*	*1050.00*	*1243.92*
32.55	52.09	54 38	60 00	1050 00	1249 02
33 24	56 16	54.68	60.00	1050.00	1254 08
33 90	60 28	54 92	60.00	1050 00	1259 10
34 52	64 43	55.10	60 00	1050.00	1264 05
35 10	68 61	55 21	60 00	1050.00	1268 92
35 63	72 81	55 26	60 00	1050 00	1273.70
36.12	77 02	55 24	60 00	1050.00	1278.39
36 56	81 24	55.16	60 00	1050.00	1282.96
36 95	85 46	55 01	60 00	1050 00	1287 41
37 28	89 66	54.79	60 00	1050.00	1291 73
38 40	93 86	54 50	60 00	1050 00	1296 76
39 36	98 03	52 55	60 00	1050.00	1299.94
40 32	102.18	53 10	60.00	1050 00	1305.60
41 28	104.16	53.59	60.00	1050 00	1309 03
42.24	106 51	54 01	60.00	1050 00	1312.77
43 20	109 87	54.38	60.00	1050 00	1317 45
44 16	113 23	56 37	60 00	1050.00	1323.76
45.12	116 59	58.36	60.00	1050.00	1330.07
46.08	119 95	60 34	60.00	1050 00	1336 38
47 04	123 31	62 33	60.00	1050 00	1342 69
48 00	126 67	62 40	60 00	1050 00	1347.07
48.19	130 03	62 40	60.00	1050 00	1350 62
48 38	133 39	62.40	60 00	1050 00	1354.18
48 58	136 75	62 40	60.00	1050 00	1357 73
48.77	140.11	62.40	60.00	1050.00	1361.28
48.96	142.80	62.40	60 00	1050 00	1364 16
49 15	145.49	62.40	60 00	1050.00	1367.04
49 34	148 18	62.40	60 00	1050.00	1369.92
49.54	150.86	62.40	60.00	1050.00	1372.80
49 73	153 55	62.40	60 00	1050 00	1375.68
49 92	156.24	62.40	60 00	1050.00	1378.56
50 30	158.93	62.40	60 00	1050 00	1381 63
50 69	161.62	62 40	60.00	1050.00	1384 70
51 07	164 30	62 40	60 00	1050 00	1387.78
51 46	166.99	62 40	60 00	1050.00	1390 85
51 84	168.00	62 40	60 00	1050.00	1392.24
52 22	169 01	62 40	60.00	1050 00	1393 63
52.61	170 02	62.40	60 00	1050 00	1395.02
52.99	171 02	62 40	60 00	1050 00	1396 42
53 38	172 03	62 40	60 00	1050.00	1397 81
53.76	173 04	62 40	60.00	1050 00	1399.20
53.76	174 05	62.40	60 00	1050.00	1400.21
53.76	175 06	62.40	60 00	1050 00	1401 22
53.76	176 06	62.40	60.00	1050.00	1402 22
53.76	178 08	62 40	60.00	1050.00	1404.24
53.76	178.08	62.40	60.00	1050.00	1404 24
53 76	178 08	62.40	60 00	1050.00	1404.24
53 76	178 08	62.40	60.00	1050.00	1404 24
53 76	178 08	62 40	60.00	1050.00	1404 24
53 76	178 08	62 40	60.00	1050.00	1404 24
53 76	178 08	62.40	60.00	1050.00	1404 24
53 76	178 08	62 40	60 00	1050.00	1404 24
53 76	178 08	62 40	60 00	1050 00	1404 24
53 76	178 08	62.40	60 00	1050.00	1404 24
53.76	178.08	62.40	60 00	1050.00	1404.24
53 76	178 08	62.40	60.00	1050 00	1404 24
2767	7865	3569	3600	63000	80802
27.67	78 65	35 69	36 00	630 00	808.02
46 12	131 09	59.48	60 00	1050.00	1346.69
0 46	1 31	0 59	0 60	10 50	13 47