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Rehabilitation of Degraded Tropical Forest Ecosystems Project

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Abstract

Tropical forests are being cleared at a rate of 16.9 million hectares per year and timber harvesting results in over 5 million hectares becoming secondary forests annually without adequate management. This decrease and degradation affect both timber production and many environmental values. Selective and clear cutting, and burning are major causes of land degradation. An assessment is needed of harvesting impacts that influence rehabilitation methods. The harvesting impacts on ecosystems vary with time and methods of logging, timber transporting methods, logged tree species, soil characteristics, topographies, local rainfall patterns etc., and must be assessed in a range of conditions with long term monitoring. Increased supply of wood from plantation forests has the potential to reduce pressure on natural forest resources as well as contributing to environmental care and economic advancement for landholders. Short-rotation plantations can result in changes in nutrient storage and cycling processes due to factors such as harvesting wood, fertilisation, erosion, leaching, and modified patterns of organic matter turnover. These factors can affect storage and supply of soil nutrients for tree growth and consequently the sustainability of plantation systems. Opportunities exist to manipulate soil organic matter through silvicultural practices but these must be technically feasible, economically viable and socially acceptable. The following research objectives are proposed: (1). evaluation of forest harvesting and fire impacts on the forest ecosystems, (2). development of methods to rehabilitate logged-over forests, secondary forests and degraded forest lands, (3). development of silvicultural techniques on plantation and degraded lands, (4). network on the rehabilitation of degraded tropical forest ecosystems. It is anticipated that the results of these studies will contribute to the sustainable use of forest resources and environmental conservation.

BACKGROUND AND JUSTIFICATION

There are 4.5 billion hectares of forests of which 3% are in the tropics. Tropical forests have been affected severely by human activities resulting in their rapid reduction in size and quality. Apart from the estimated 16.9 million hectares lost annually mainly through conversion for agriculture and shifting cultivation, more than 5 million hectares have become secondary forests after harvesting. These secondary forests lack adequate management and silvicultural treatments (Forestry Agency and ITTO 1991). Tropical forest loss and degradation affect not only timber production but also local and global environments and are causes of flooding, erosion, landslides, desertification and other natural disasters.

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The potential loss of biological diversity, which could be as high as one quarter of all species of plants, animals, fungi and micro-organisms on the earth over the next 25 years, threatens the sustainable and harmonised development of the global ecosystem. Reduction of the tropical forest is also related to global warming through acceleration of the greenhouse gas emissions such as carbon dioxide, methane and nitrogen oxide and accumulated decrease of carbon dioxide through photosynthesis by tropical trees (Kira 1991, Uchijima 1991).

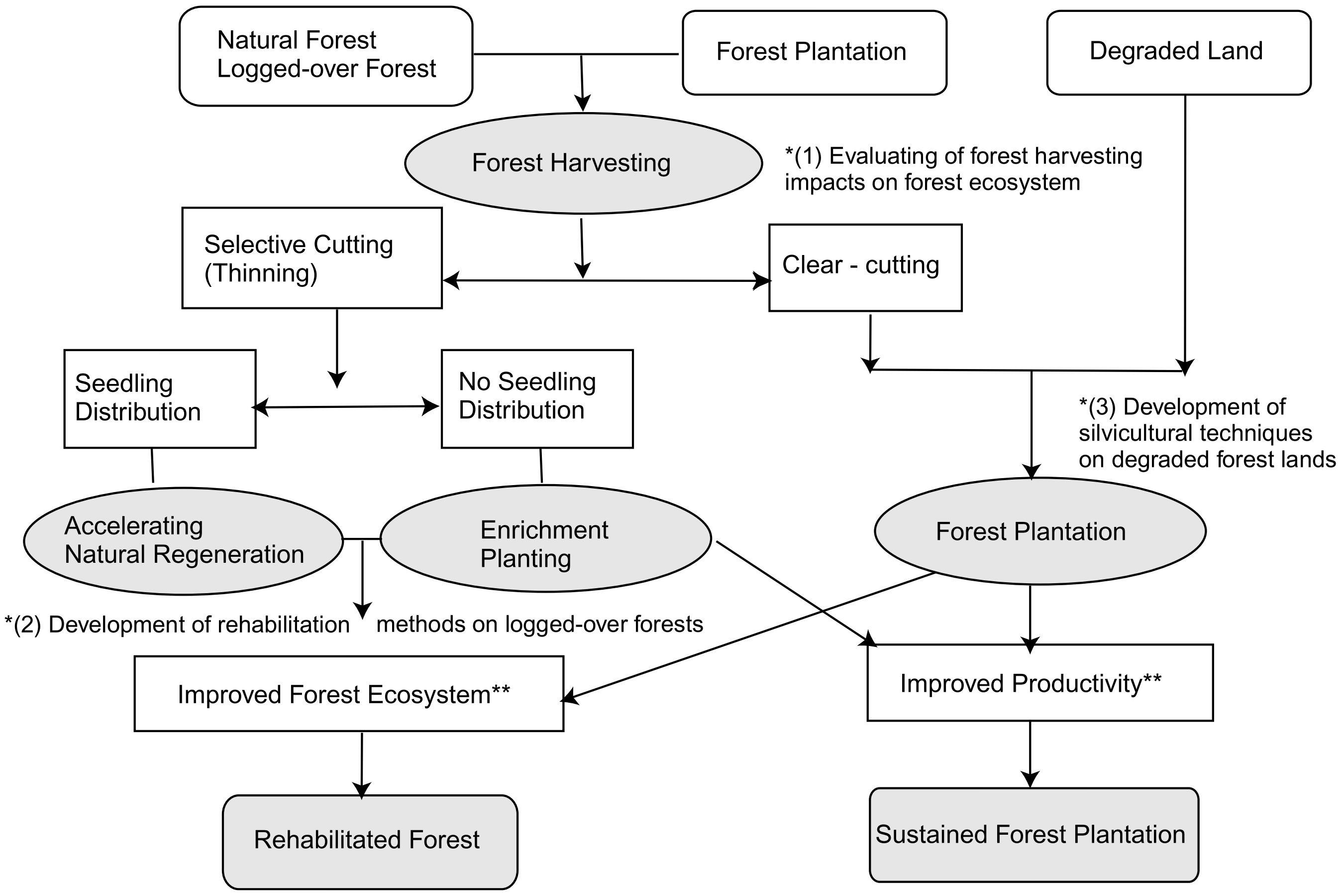
The harvesting of timber affects forest ecosystems in various ways which include site degradation, reduced forest water supply, soil loss and greenhouse gas emission. Selective and clear cutting, fire and burning are major causes of land degradation, and forest harvesting becomes a trigger for other forms of land utilisation (Kobayashi 1988, 1994). While forest harvesting affects changes in ecosystems, subsequent land utilisation may cause more severe impacts on natural ecosystems (Fig.1).

The effects of forest harvesting and fire have not fully been understood, especially in tropical rainforests (Lamb 1990). Information on the long-term impacts of tree harvesting and fire on forest ecosystems especially with regard to changes in vegetation, soil and productivity, is lacking. Rehabilitation of degraded forests and lands is a most urgent matter requiring enrichment of ecosystems and sustainable use of degraded areas at regional and global scales. In a logged-over forests, where former ecosystems more or less remain, the development of methods to accelerate natural regeneration is needed (Forest Agency and ITTO 1991). Where little or none of the natural ecosystem remains, plantations, site management and productivity must be considered. Successful regeneration and reforestation depends on the accurate evaluation of site conditions created by harvesting, e.g. the success of natural regeneration by commercial tree species is strongly influenced by the intensity of harvesting. Studies of biological and physiological characteristics of regenerated trees or newly planted trees and of the processes influencing productivity are necessary improve the success rate of rehabilitation and reforestation activities.

In the Asia Pacific region rainforests decreased from 325 million ha in 1980 to about half this value by the mid 1990s and are projected to decline to 30-35 million ha in another decade (Tiarks *et al.* 1998). At the same time population growth and rapid economic expansion in the region has escalated demand for industrial wood products and fuelwood. Increased supply of wood from plantation forests has the potential to reduce pressure on natural forest resources as well as contributing to environmental care and economic advancement for landholders in the tropics.

Many soils of tropical forest ecosystems are poor in nutrients. Nevertheless, undisturbed natural forests do not usually display symptoms of nutrient disorders because nutrient cycles are in a state of dynamic equilibrium where inputs and outputs of nutrients are in balance and plant demand for nutrients is met by efficient recycling systems. Where natural forests are replaced by short-rotation plantations there will be changes in nutrient storage and cycling processes due to factors such as harvesting wood, changed organic matter quality, fertilisation, erosion, leaching, and modified patterns of organic matter turnover. These factors can affect storage and supply of soil nutrients for tree growth and ultimately the sustainability of plantations. Studies on the effects of monoculture plantations on organic matter dynamics and nutrient cycling have usually found changed patterns of organic matter and nutrient storage (Evans 1992, Jordan 1985, Kobayashi 1994). There is concern that short rotations of some species in plantations will not be sustainable in the long-term. Long-term sustainable production will rely on management practices which maintain soil organic matter, conserve nutrient stores and minimise direct nutrient loss. There is critical need for designed experiments which evaluate silvicultural options, especially at the phase between harvesting and control of the site by the replacement trees. In particular, the research must focus on ecosystem variables and functional processes which will allow quantitative assessment of plantation management and its likely long-term impacts.

Figure 1. Rehabilitation of Degraded Tropical Forestry Ecosystem



* Actual target is development of adequate techniques.

** Final target is conservation of biodiversity and environment of forest.

Pulpwood in particular is a low value, high volume product and the industry is characterised by large areas under short rotation with high volume tree crops. It is this type of plantation management that is most likely to exert excessive demands on the site, and hence it is highly appropriate for studies addressing issues of sustainability. The challenge for researchers is to provide the scientific information that enables managers to devise silvicultural systems for plantations which enhance soil properties important to sustainable production and minimise deleterious effects associated with short rotation tree crops.

Based on this evaluation, in 1994 the following research topics and international network were proposed (Fig. 2) which would contribute to the sustainable use of forest resources and environmental conservation:

- Evaluation of forest harvesting and impacts of fire on the forest ecosystems;
- Development of methods to rehabilitate logged-over forests, secondary forests and degraded forest lands;
- Development of silvicultural techniques on plantation and degraded lands; and
- Network on the rehabilitation of degraded tropical forest ecosystems.

Increasing the area of rehabilitated forest lands will contribute to the area of forests, the sustainable development of forest resources, the conservation of primary tropical forests and the environment improvement (Figs. 3 and 4).

STUDY 1: EVALUATION OF FOREST HARVESTING AND IMPACTS OF FIRE ON FOREST ECOSYSTEMS

Large areas of forest land remain degraded after harvesting and fire in the tropics in the form of logged-over forests, abandoned shifting cultivation areas or wastelands. In these areas various methods of harvesting have been employed under various conditions. These lands are in various stages of degradation and there is a range of techniques which could be developed to assist their rehabilitation. Although a number of reforestation trials have recently been started for the purpose of regeneration of useful tree species, plantation and even recovery of former forest ecosystems, many of them are empirical “trial and error” type of activities. Few are sufficiently systematic and scientific.

Assembly and analysis of data in relation to harvesting impacts which significantly influence rehabilitation methods is needed. Harvesting impacts on ecosystems vary with time and methods of logging, timber transporting methods, logged tree species, soil characteristics, topographies, local rainfall patterns, and others. So, the impacts in relation to logging and timber transportation measures must be assessed in a range of conditions with long-term monitoring.

Objectives

The overall objective of this study is to evaluate past, ongoing and future harvesting impacts on forest ecosystems. The results will contribute to the knowledge base on which to develop rehabilitation of degraded forest ecosystems. More specifically the studies will:

- Evaluate logging and yarding methods, and forest fire on disturbance of forest ecosystems;
- Analyse the demography of regenerated trees populations; and
- Model a/de-gradation processes in forest ecosystems.

One study will offer the basic and reliable information for making guidelines of harvesting activities in future management of tropical forests by scientific investigation of the degradation process. The investigation covers a wide range of analyses on degradation process of flora, fauna and site factors, so that information obtained will be relevant for the development of rehabilitation techniques both in logged-over and plantation areas.

Regeneration of tree species after harvesting is most important in the recovery of forest ecosystems, so that investigation will focus on

Figure 2. The dynamics of tropical secondary mixed deciduous forest with bamboo. Fire and pioneer population will controle direction of this secondary forest dynamics without the convertion of land utilization

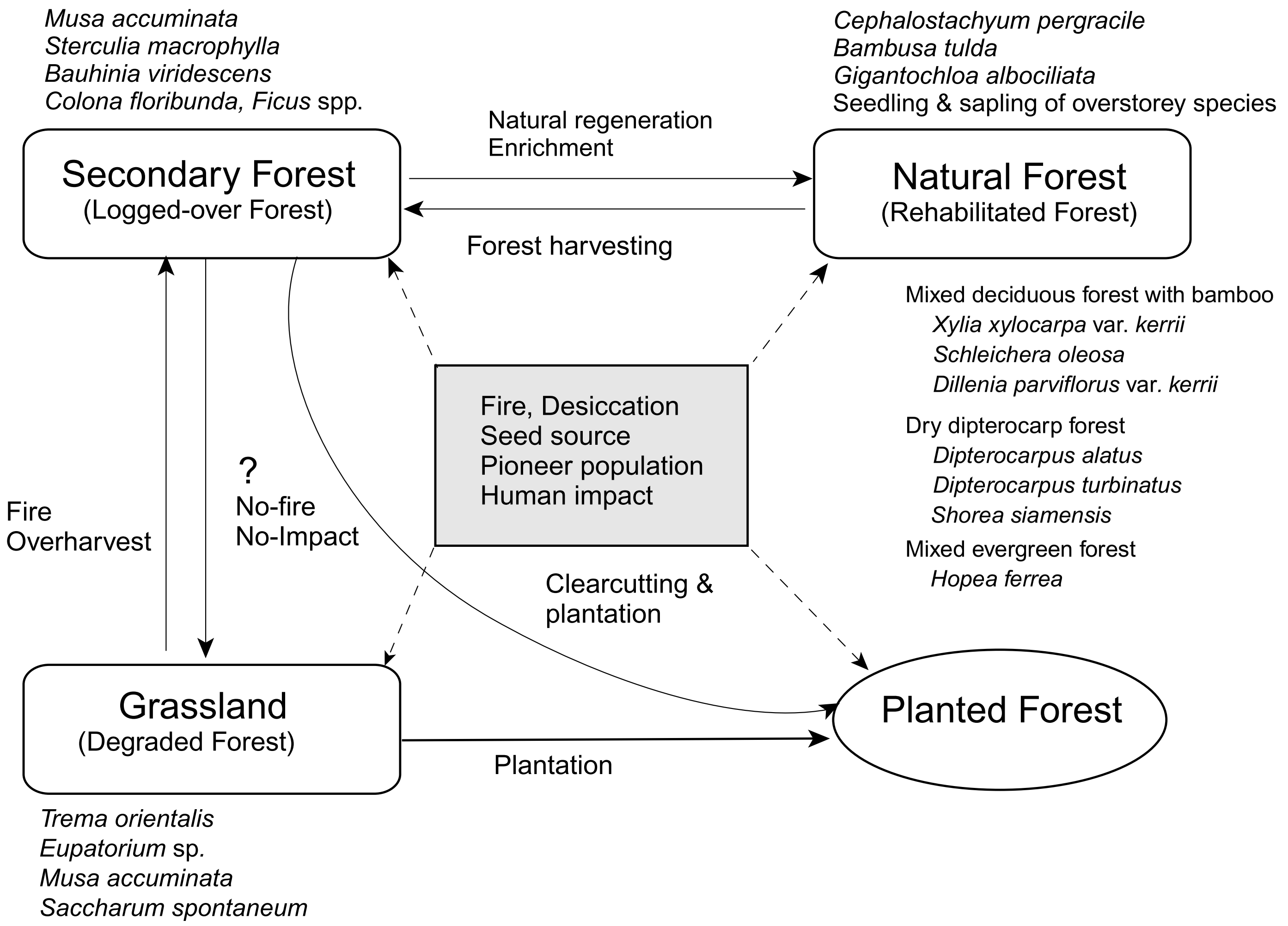


Figure 3. Rehabilitation of degraded burnt forest

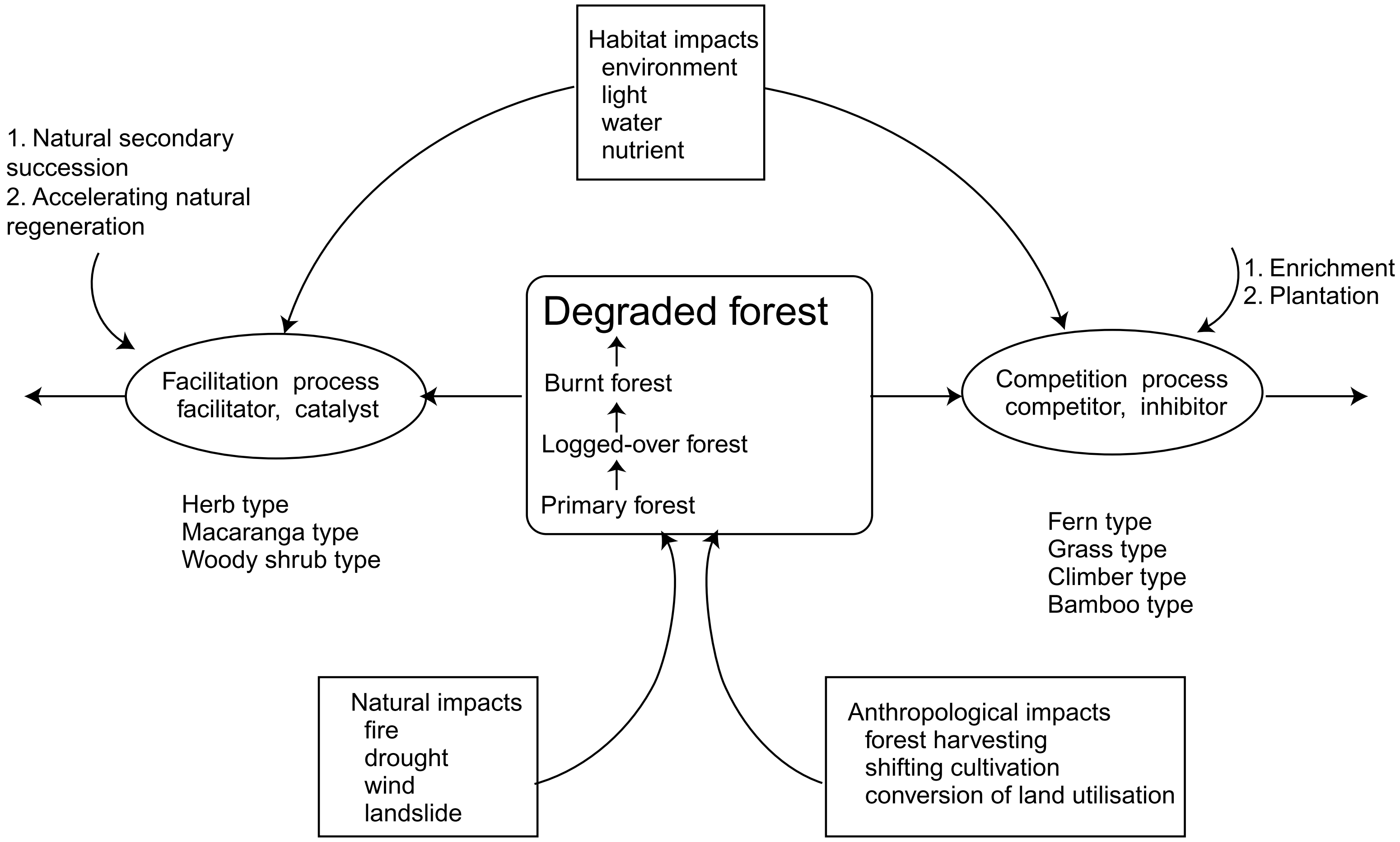
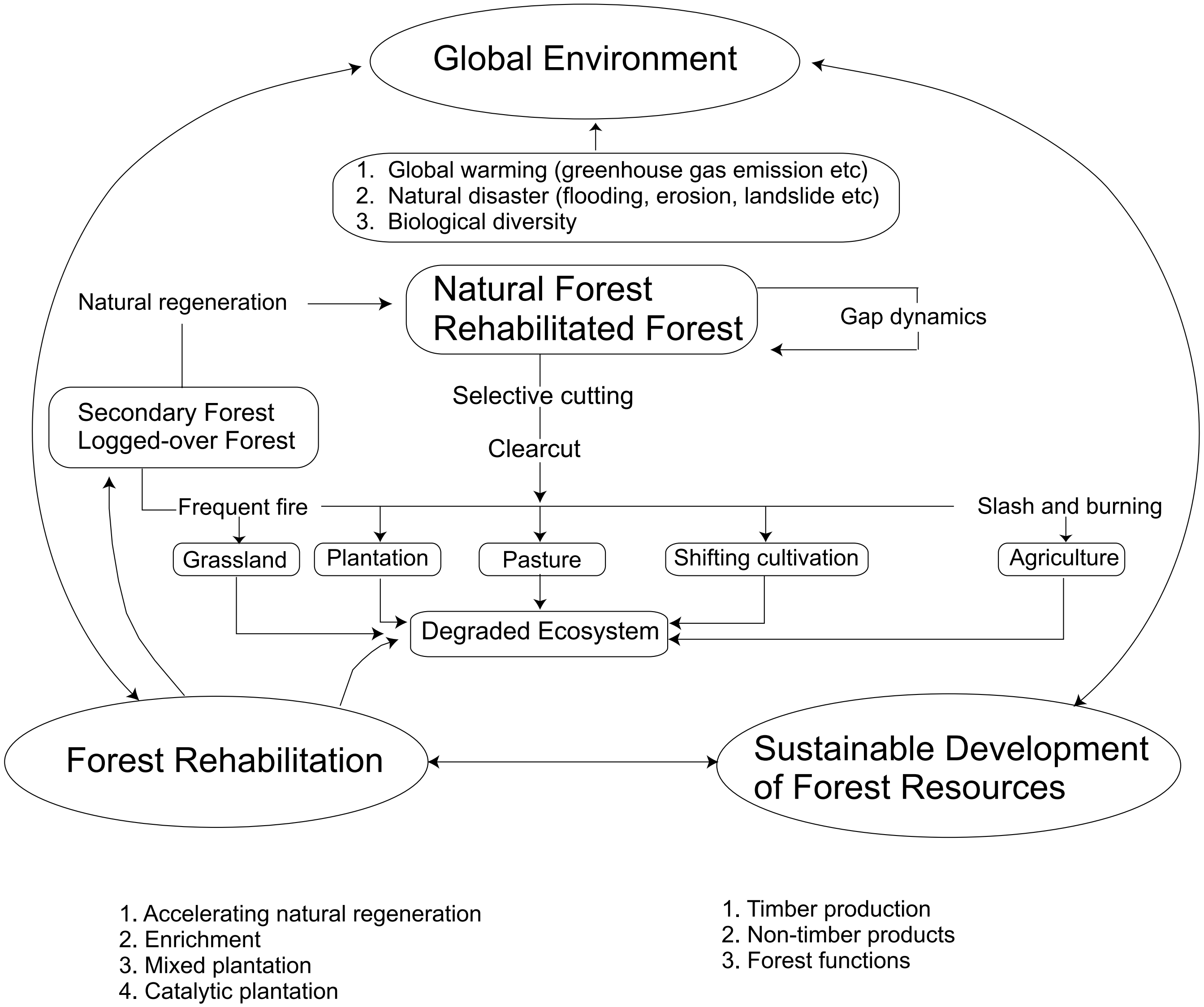


Figure 4. Rehabilitation of Degraded Forest Ecosystem (Forest Resources Chain)



demographic analyses of regenerated tree population including felled or damaged tree species. The study results will give fundamental information for development of gap planting or enrichment planting methods.

Prediction of degradation process of forest ecosystems by simulation models is also necessary. The key factor(s) controlling the processes will be determined.

Methodology

Evaluation of logging, yarding methods and forest fire on disturbance of forest ecosystems

Experimental plots will be set in the logged-over and/or burnt forests with various degrees of degradation in representative vegetation in each region. Investigation will be focused on the recovery of ecosystems in relation to the intensity of harvesting and fire. Selective cutting and yarding, either in experimental or commercial scales, are required in the experimental plots. Harvesting operations and their effects on ecosystems in various regions will be measured and analysed throughout the project.

Main items for this study at each location are:

(i) to identify and categorise the harvesting methods which have been or are being employed with items of logging and timber transporting measures, harvesting intensity such as the volume of trees harvested and areas opened, and then following human activities.

(ii) to determine the change of ecosystems before and after harvesting by monitoring:

- Forest structure, particularly, size, distribution and spacing of trees;
- Vegetation dynamics including composition, mortality, growth rate, etc;
- Biomass;
- Soil characteristics determined by soil structure, physical properties such as hardness, thickness, pore composition, saturated hydraulic conduction, bulk density soil water tension etc. and chemical properties such as pH, C-N contents,cation exchange capacity, etc;
- Microclimate such as air and soil temperature, moisture, precipitation, light intensity, etc; and
- Forest fauna in relation to regeneration of trees.

Demographic analyses of regenerated tree populations

Experimental quadrats will be set in the plots mentioned above for demographic analysis of population dynamics of regenerated trees for monitoring:

- Mortality of advance growth;
- Dynamics of seed dispersal and coppice growth;
- Growth rate (height, internode length, leaf number, diameter) of seedlings related with light and water regime; and
- Genetic constitution of the surviving seedlings.

Modelling of a/de-gradation process of forest ecosystem

Simulation models will be made by quantifying the evaluation of harvesting methods on disturbance of forest ecosystems and by the data obtained from monitoring of ecosystem changes.

Expected Results

- Forest harvesting impacts of the logging and timber transportation methods on forest ecosystems will be identified and indicators provided to guide harvesting activities in relation to regeneration. They will provide an indication of whether logging practices are contributing to the impoverishment of the gene pool of regenerated tree species;
- Practices which negatively influence forest ecosystems will be identified in different areas and basic information provided for

rehabilitation techniques and sustainable management of tropical forests; and
- Improved low impact forest harvesting techniques will positively influence the global environment through increased carbon sequestration.

STUDY 2: DEVELOPMENT OF METHODS TO REHABILITATE LOGGED-OVER FORESTS, SECONDARY FORESTS AND DEGRADED FOREST LANDS

About 5 million hectares of natural tropical forests are annually degraded to logged-over forests. Rehabilitation of these degraded forests along with sound concepts of sustainable management are needed urgently (Thang 1987). The main rehabilitation question is how to create the appropriate growing conditions, particularly light conditions for each species from juvenile to mature stages (Weidelt and Banaag 1982).

"Forest patch improvement" may be a promising method to accelerate natural regeneration (Kobayashi 1988). More effort is put into the patch than into the surroundings. Treatment is limited to ensuring adequate light intensity and regulating inter-specific competition in the patch. It can be employed where seedlings are present or seed is available of target tree species, otherwise "enrichment planting" must be undertaken. "Line planting" and "gap planting" are typical methods of enrichment planting. Both methods have often been incorrectly considered to be more costly and labour-consuming than the clear-cutting and plantation method. Also, there has been reluctance to use them since adequate subsequent tending has often not been carried out. However, enrichment planting is a promising means of sustainable management of tropical forests as it provides potentially suitable growth conditions for the tree species to be regenerated (Whitmore 1975).

In both methods it is necessary to determine how to provide and maintain appropriate light intensities which may differ with the growth stages of each target species. These treatments take advantage of the remaining biomass and ecosystem.

Objective

To provide strategic information on which to base techniques to accelerate natural regeneration and for enrichment planting.

Methodology

Seedlings on forest floors are distributed in a mosaic pattern around their mother trees. They do not receive sufficient light because upper trees prevent it from penetrating into the understorey. To improve light conditions for the seedlings, substorey and understorey of non-commercial species are removed. This treatment, "Forest patch improvement", should be carried out in logged-over forest to increase the survival and growth rate of seedlings of commercial species. When the seedlings reach a height of 3-4 m, the overstorey is harvested for commercial use.

(i) Treatments:

- Size of experimental plots will be more than 200 m x 200 m. Two plots of 1 ha (100 m x 100 m) each will be treated to have two levels of light intensities (e.g. 15% and 30%) on their forest floor by removing the substorey and understorey vegetation;
- Small quadrats (2 m x 2 m) will be set up to monitor seedling growth; and
- Upperstorey will be harvested when the seedlings reach 3-4 m.

(ii) Items to be monitored include:

- Seedling dynamics: distribution, seed fall, germination rate, mortality, height growth, stem growth, branching, leaf number and area, first internode length, species composition of forest floor;
- Standing trees: species composition, height growth, diameter growth, mortality,

standing position, crown diameter, phenology, litter fall, flowering, fruiting;

- Microclimate: crown temperature, air temperature, soil temperature, rainfall, throughfall, stem flow, soil water tension, forest floor light intensity; and
- Soil condition and nutrient cycling: soil compaction, soil water tension, soil physical properties, litter decomposition rate, carbon, nitrogen, pH, CEC exchangeable cations.

(iii) Techniques:

- Litter and seed traps to survey the seed dispersal;
- A photosynthesis meter to measure seedling photosynthesis and a pressure chamber to survey the water regime in seedlings;
- A data logger and personal computer to record microclimate; and
- A light meter to measure relative light intensity on the forest floor.

Enrichment planting methods will be developed on sites where harvesting operations will be undertaken. The existing ecosystem will be characterised in advance of the operations. Experimental plots for both line planting and gap planting will be in areas where seeds or seedlings of target tree species are lacking. Seeds or seedlings to be planted will come from either neighbouring areas or nurseries. Both line- and gap-planting will be studied.

(i) Treatments for line planting:

- Lines will be set on the west-east direction with width determined in relation to the height of substorey (e.g. 3, 5, and 10 m);
- Distance between lines will be 10-15 m; and
- Tree species in the area and several other commercial species will be selected for planting. Wildings will be planted if they are available.

(ii) Treatments to be taken for gap planting:

- Gap size will be 10 m x 10 m.
- Two gap densities (e.g. 5 gaps ha^{-1} and 9 gaps ha^{-1}) will be tried.
- Tree species suitable for the site condition will be selected. Wildings may be applied.

(iii) Items to be monitored and techniques used are the same as for enrichment planting.

Expected Outputs and Benefits

(i) Mode of seed dispersal and seedling establishment of each tree species for rehabilitation in the degraded site will be identified. The results will be useful for selection of species to be regenerated.

(ii) Initial growth patterns of useful tree species will be identified. The results will provide useful information about which key factors should be controlled.

(iii) The minimum treatment intensity will be identified, which is the main way to decide whether the method is practical or not.

STUDY 3: DEVELOPMENT OF SILVICULTURAL TECHNIQUES FOR PLANTATIONS ON DEGRADED LANDS

Forest plantations in the tropics will play a very important role on the world wood supply in the future. Moreover, they can relieve the pressure to exploit natural forests if rates of reforestation substantially increase (Evans 1992). Plantation forestry has recently started in many tropical areas but the knowledge of nursery and planting techniques is limited to the fast-growing trees, such as *Eucalyptus, Acacia* and *Pinus* species, and a few other commercial species. However, there are many native tree species, some of which may possess characteristics making them suitable as plantation species. Development of research on seedling production and planting methods of these lesser-known species is a priority in many tropical countries.

Another problem is how to improve and maintain productivity of forest plantations. Many plantations are established on soils that are very low in nutrients and/or susceptible to degradation. Although the plantation has a potential of high productivity, it may have low yields and degrade the site if managed poorly. Information is urgently required on the factors that control the productivity of plantations under a wide range of soil and environmental conditions, and on ways of managing the site to maintain the productivity of successive tree crops (sustained productivity).

Ecological, social and economic constraints must be considered when management options are determined. Difficult social problems in some places have prevented or inhibited the establishment of plantations or the implementation of new techniques. Complementary research on socio-economic problems is highly desirable to ensure the technical solutions to the problems can be effectively adopted.

Overall Objectives

- Development of species-site matching methods, identification of critical silvicultural characteristics and establishment techniques for lesser known indigenous species.
- Site management options for sustained productivity of plantations.

SPECIES-SITE MATCHING METHODS

In the Amazon region about 42 million hectares of forest have been cleared and some 50% of the 17.5 million hectares of pasture is degraded forest land (Serrao 1990) caused mainly by inappropriate methods of establishment and management of those pastures (Kitamura *et al.* 1982, Serrao and Homma 1982). Forest tree plantations are very important to improve/recover soil conditions to promote sustainable productivity. Correct species-site matching is one of the critical operations in successful establishment of forest plantations and is particularly difficult for lesser-known indigenous species.

The study will use PLANTGRO which is a software package developed originally at CSIRO, Australia. PLANTGRO has been used to predict plant growth but the data sets are mainly for better known species, usually exotics, in Asia. It is based on a set of climate, soil and plant files, which may be added or edited by the user. It will also support further development of TROPIS (Tree Growth Potential Information System) by CIFOR to provide an index of sources of permanent plot data relevant to the tropics and to provide expert systems to assist species selection and site matching.

Objectives

- To adapt PLANTGRO to the Amazonian conditions using existing data.
- To enhance the performance of PLANTGRO, based on field and glasshouse experiments.
- To provide expert systems to assist species-site matching.

Methodology

- Collect data and information from existing field trials in the Amazonian region.
- Select a group of potential forest tree species for plantation in degraded forest land in the region.
- Set up climate and soil files for the existing and potential experimental/plantations areas.
- Set up plant files, establishing the response of each species in relation to soils and climate variations, based on local experts information.
- Calibrate plant/climate/soil files based on results of PLANTGRO analysis using existing data.
- Establish nursery and glasshouse trials to measure critical silvicultural attributes.

Expected Outputs and Benefits

- Plant, soil and climate files, based on existing data, to be used with PLANTGRO to select forest tree species for degraded forest lands in the Brazilian Amazonian Region.
- Technical meeting in Manaus (Amazonia) to present the results of this initial project.

- A version of PLANTGRO adapted for Amazonian species and containing plant files with high quality data. This will be used for species-site matching in the region.
- A more comprehensive tree growth potential information system that will assist species-site matching and indigenous species' domestication.

REHABILITATION OF DEGRADED FOREST AREAS WITH INDIGENOUS SPECIES IN MALAYSIA

There are 20 million hectares of forests managed for production, conservation and protection purposes in Malaysia. The Selective Management System, which allows for minimal site disturbance through limited number of trees harvested per hectare, is considered a sound management strategy. However, some of the forest ecosystems have been degraded by improper harvesting by loggers and shifting cultivation. More than 4 million ha of the forests have been denuded by shifting cultivation, tin mining and other practices in recent years. There have been intensive efforts by various forestry related agencies to rehabilitate the denuded areas with fast-growing exotic tropical species and indigenous tree species. Some of the trials have given positive results, while others have performed poorly, which may be attributed to inappropriate planting strategies.

The proposed project will be carried out to re-examine indigenous tree species with potential for rehabilitation as well as for plantation purposes. Several planting techniques (based on experiences in Bintulu, Sarawak and other trials through out Malaysia) will be tested for each species to find the most suitable silvicultural techniques. The results will serve as a model for rehabilitation of degraded tropical rainforest ecosystems in the country and the region.

Objective

The specific objectives of this study are to:

- identify potential indigenous tree species suitable for rehabilitation and for plantation purposes;
- determine the appropriate planting strategies;
- examine the species-site relationship;
- develop guidelines for rehabilitation efforts in similar degraded areas; and
- assess the socio-economics of rehabilitation.

Materials and Methods

The project will be carried out in Pasoh Forest Reserve in Negeri Sembilan. The site is located approximately 80 km from Seremban, the state capital of Negeri Sembilan. The 60 ha area, previously covered by *Intsia palembanica*, balau (*Shorea* sp.) and *Dipterocarpus* sp., was logged in 1984.

Indigenous tree species, such as *Shorea leprosula, S. curtisii, S. parvifolia, S. maxwelliana, I. palembanica, Hopea beccariana,* will be tested. Seedlings and wildings will be nurtured and raised in a new nursery in Simpang Pertang. The seedlings will be planted using various techniques - open planting (with and without site preparation), planting under nurse trees (pioneer species e.g. *Acacia* spp.), line planting, gap planting, etc. Some experiments will involve the use of fertilisers, and planting of leguminous cover crops between the seedlings to improve fertility and prevent soil erosion. Data will be taken from several permanent sample plots to be set up within each planting technique.

Expected Benefits

The study will identify indigenous tree species with potential for rehabilitation and plantation purposes and indicate suitable planting strategies. The results will provide forest managers and policy makers with options in making decisions on the management of disturbed and degraded tropical rainforest ecosystems.

MANAGEMENT OPTIONS FOR SUSTAINED PRODUCTIVITY OF FAST-GROWING PLANTATIONS

The general objective of this study is to develop sound scientific principles, develop management options and demonstrate the value of sound forestry practices under different environments in a multi-national context. This research, while distinct and independent, will form part of a large CIFOR-coordinated international experiment involving many organisations and species. At each location, the experiment is designed to meet the following specific objectives:

- Evaluate the impact of soil and site management practices on the productivity of successive rotations of plantations. Crop cycles may consist of plantations grown for pulpwood, poles, sawn timber or fuelwood. The treatments proposed are designed to cover the extreme of management practices so the boundaries of impacts can be established.
- Develop management options for maintaining or increasing productivity. Sufficient information will be gathered so that the impact of each option on soil and associated environment can be measured. This information should allow tree growers to select and adapt options to their specific conditions and to demonstrate the present and future consequences of undesirable practices.
- Strengthen local institutional capacity to respond to new problems and opportunities. The partnership will enhance the experience and capability of all participating organisations. Local partners should be better equipped to offer quick response, local knowledge and long-term institutional memory to changing social, financial and ecological conditions than outside organisations.

Experimental Approaches and Methodology

The approach of the project is to include a set of treatments common at all locations and additional treatments tailored to each site, depending on local management concerns, soil and forest conditions and productivity objectives. The common measurements will allow integration of the results between sites and better understanding of the processes. The experiment will be located on sites with soils that are representative of a wide area. Treatments, plot sizes and sampling will be designed to detect a 15-20% difference in productivity. The choice of tree species depends on local management concerns or site conditions. Some species used will be exotics, others will be native to the country where the experiments are located.

The experiment at each site will be based on a set of common treatments and site-specific treatments. The approach proposed here was based on the experience of research on sustained productivity in other ecosystems (Tiarks *et al.* 1998). It will be set up during the harvesting of a crop. The common treatments will be incorporated in a 3 x 2 factorial design with three levels of organic matter manipulations and two levels of weed control giving a total of six treatment combination. In addition, an uncut area close to and representative of the harvested stand will be left as a control for comparison and for measuring changes in soil and other site properties. The levels of organic matter are:

OM_0	Stemwood + bark harvested. Stand is felled and the tops and branches are cut and remain at the stump location. Only the commercial sized boles and associated bark is removed from the plots. All other organic residue is left undisturbed.
OM_1	Whole tree harvest. All above ground components of the commercial sized crop trees are removed.

OM_2 All above ground organic residue including the crop trees, any understorey, and litter is removed from the plots. Where present, the soil organic matter (organic residue that is decomposed beyond recognition) on the surface is not disturbed.

The two vegetation control treatments are:

V_0 All vegetation retained. The natural vegetation is retained and is allowed to develop. However a minimal vegetation control to ensure 100% survival of the crop trees is required.

V_1 Total vegetation control. All ground and understorey (non-crop trees) are controlled by mechanical removal, herbicides, or a combination until canopy closure.

The site-specific treatments: At each study location these will be selected on their potential to enhance productivity, increase the understanding of basic process, and to answer questions that may be posed in the future. Examples of variables that may be used are:

1. Treatments that might influence soil density such as compaction from harvesting equipment and amelioration from tillage. Levels could be reduced bulk density from tillage, normal bulk density by using non-impact harvest methods, and increased bulk density by heavy harvesting equipment.
2. Nutrient input treatments including fertiliser application, intercropping with legumes, and organic residue (including waste) applications. Levels may be two rates of two nutrients, several rates of one or with and without intercropping.
3. Species mixing treatments, either spatially or temporally which may include using a short rotation nurse crop to establish another or growing an annual crop between rotations of trees. Levels may be presence or absence or a second species.
4. Burning as a site preparation technique. Levels could be different amounts of fuel (biomass) and/or different burning intensities, depending on weather conditions.
5. Best practices: a package of practices based on the best current knowledge and experience on similar sites. New, untested techniques should not be used in this long-term trial until they have been validated in other experiments.

In addition to the above treatments, species mixing trials for establishing a species- rich forest which consists of similar structural components, such as species composition and spatial pattern of trees, to those of a typical natural forest around the study site. This experiment aims to construct a pseudo-natural forest artificially as the opposite extreme to monoculture plantations.

SOCIAL AND ECONOMIC ACCEPTABILITY OF MANAGEMENT OPTIONS

In developing strategies and design for forestation with certain management options, attention should be paid not only on the direct objective of various forest output, but also on more general and indirect objectives for society or for forest management entities. From a societal point of view, not only the potential direct outputs are of importance, but also the degree to which they can contribute directly or indirectly in achieving societal objectives like meeting basic needs, economic growth and equity, creating employment opportunity and self-reliance.

Methodology

To analyse the degree to which direct and indirect objectives are met, and to choose among alternative forestation designs, a diagnostic approach could be applied under the different local conditions. A variety of general diagnostic methodologies is available, such as analysis of environmental impact or farming systems and several methods of economic assessment. When possible management options are determined, they can be assessed to decide their relevancy within local social and economic conditions.

Expected Results

- Various constraints of specific management options that relate to human resources, or to political, institutional and cultural consideration will be identified. The results will provide the basis for assessment of a feasibility of management options and redesign for alternatives.
- Probable economic and financial effects of a specific management option will be assessed, to provide indications of economic acceptability for entities involved or for society at different levels.
- Major environmental and social effects, particularly indirect and long-term effects will be identified. The results will provide indications of the nature and level of impacts of management options with obvious flaws.

INTERNATIONAL NETWORK ON THE REHABILITATION OF DEGRADED TROPICAL FOREST ECOSYSTEMS

The international network will exchange and synthesise the internationally-based scientific and technical information from the CIFOR/Japan project on the rehabilitation of degraded tropical forest ecosystems. Final outputs are expected to contribute to the long-term monitoring in degraded forest ecosystems. The network information system and data base will be created using the Internet. This system will contribute to research capacity building and development of the rehabilitation techniques, and also provide information to policy makers, forest managers, small stakeholders and local community.

Relevant existing networks are: for forest restoration - IUFRO Division.1.17.00 (John Parrotta, David Lamb); rehabilitation - FORSPA (Simmathiri Appanah); site management of plantations - CIFOR (Christian Cossalter); rehabilitation – Seoul University (Don Koo Lee); rehabilitation of Mekong River Basin – University of Queensland (Don Gilmour); restoration – CATIE (Florencia Montagnini), rehabilitation – University GH-Paderborn (Andreas Schulte); Society for Ecological Restoration, etc. Linkage to these networks is needed for syntheses of specific information.

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2

Rehabilitation of Degraded Forests in Lowland Kutai, East Kalimantan, Indonesia

T. Mori[1]

Abstract

Undisturbed lowland primary forest in Kutai, East Kalimantan is usually distinguished by dominance of dipterocarp species in number of individuals, in basal area and by their emergence to more than 50 m in height. Forests in most lowland concession areas have been logged selectively and suffered from surface forest fires at least twice since 1970. Canopy height and dominance levels have decreased in proportion to extent and frequency of disturbances by logging and fires but the area of pioneer species has increased proportionally with degradation. Secondary forest species or pyrophytic trees have become dominant in all forest lands. Forest degradation in lowland Kutai is more serious than where forest has had only commercial logging. Rehabilitation methods should be tailored to existing forest structures; e.g., natural regeneration is most appropriate in forest dominated by primary species, and enrichment by patch planting in gap sites in forest with few mother trees. *Macaranga* forest or pyrophytic shrub forest should be artificially planted. This paper focuses on planting dipterocarps. Generally single species plantations of dipterocarps should be avoided, except for a few species e.g. *Dryobalanops aromatica* and *Shorea robusta*. When dipterocarps are used, the key to success for successful dipterocarp planting is light control and species choice. Light control should correspond to the light requirements of a species during its growing stages, so planting methods should reflect site conditions and growth characteristics of the species. These characteristics vary widely among dipterocarp species. Degraded forest types in East Kalimantan and rehabilitation measures for them are reviewed.

INTRODUCTION

Forest degradation is a kind of canopy gap forming process and/or retrogressive actions against plant succession process caused by natural disasters and human activities. Causes of forest degradation include strong winds, volcanic eruptions, epidemic pests and diseases, flooding, wildfire, logging and shifting cultivation. Along the roadsides in East Kalimantan is a mosaic of vegetation, *Imperata cylindrica* grasslands, pyrophytic forests in fallow land, secondary forests with tall, standing, dead dipterocarp trees due to the large forest fires and selectively logged-over dipterocarp forests. Major factors of forest degradation are agricultural exploitation, commercial logging and wildfire (Mori *et al.* 2000).

Forest rehabilitation is human intervention to counter forest degradation processes, e.g. promotion of the recovery process in large gaps of dipterocarp forest or conversion of shrub forest to high storey plantation forest. Forest rehabilitation can be defined as promoting measures that maximise forest functions to satisfy human aims. The forests are managed for many purposes, including biodiversity conservation, carbon sinks, soil and water conservation, wildlife

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conservation, timber production and needs of local people. Each purpose sometimes requires conflicting rehabilitation measures. This paper deals with rehabilitation measures aimed mainly at forest production rather than biological or ecological purposes. It reviews characteristics of degraded forest in East Kalimantan and potential rehabilitation methods for them. Schulte and Schöne (1996) and Appanah and Turnbull (1998) have made general reviews of silviculture and management of dipterocarps.

DEGRADED FORESTS

Before 1980 primary dipterocarp forest might have been typical undisturbed forests of the lowland tropics, but now it is very difficult to find such forest. An example of change in composition and biomass between primary and degraded forests is shown in Table 1. Undisturbed primary forests in East Kalimantan have high species diversity, tall emergent trees and a large biomass (Kartawinata *et al.* 1981a,b, Proctor *et al.* 1983, Sukardjo *et al.* 1990, Sist and Saridan 1998). The tallest trees are 60-70 m in height, the basal area reaches 35 m^2 ha^{-1}, and aboveground biomass exceeds 400 t ha^{-1} (Yamakura *et al.* 1986).

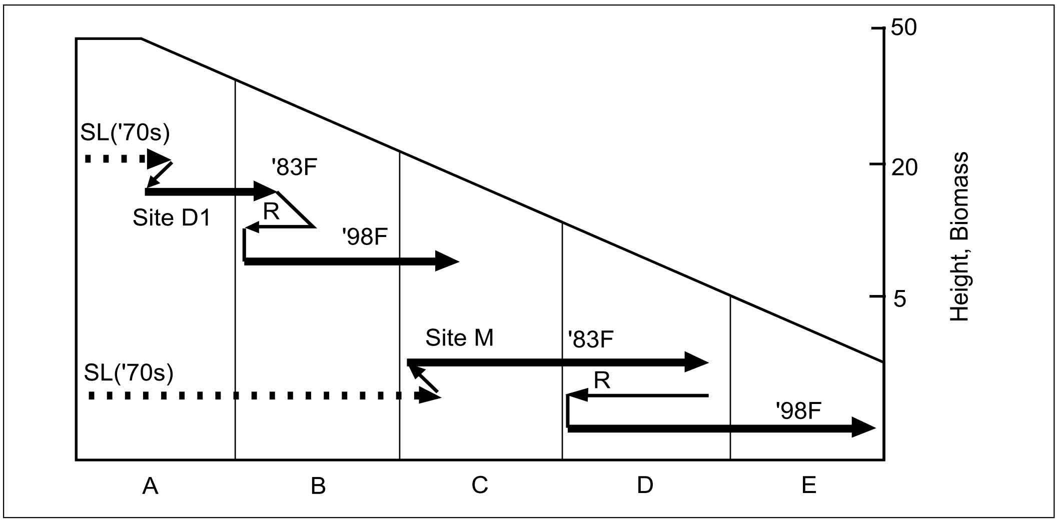
Compared with these primary forests, many forests currently in Bukit Soeharto Forest Reserve area are degraded to various extent. Table 1 shows three typical forests as examples: lightly degraded (D1), moderately degraded (D2) dipterocarp forests, and heavily degraded forest dominated by early pioneer tree species (M)). These degraded forests were first logged in the early 1970s and burned by surface fire in 1983. The (M) forest is located near yards of the past logging operation and many dipterocarps must have been felled. Thus this site appears to have had large gaps in the late 1970s and the fire damage in 1983 must have been very serious (Fig. 1). Then, early succession species germinated on the burned open site and *Macaranga gigantea* has become the dominant species. On the other hand, D1 has retained high species diversity with a large number and high basal area of dipterocarps. Forests similar to D1 are now very rare but D2 and M type forests are very common in the forest concession area in lowland Kutai region. These forest compositions and structures were representative before the major wildfire in 1998 which caused further degradation (Fig. 1) (Mori 2000, Toma *et al.* 2000).

Table 1. Comparison of composition and biomass between primary and degraded forests

	Undisturbed	Forests degraded by logging and fire		
	Primary	Degraded 1 (D1)	Degraded 2 (D2)	Macaranga (M)
No. of species (ha^{-1})	150 - 250	150	100	50
No. of individuals (ha^{-1})	450 - 600	300 - 400	500 - 600	500 - 600
Basal area (m^2 ha^{-1})	30 - 40	25 - 30	25 - 30	20
Dipterocarps				
No. of individuals (ha^{-1})	90 - 130	50	40	15
% of basal area	45 - 55	40	30	10
Pioneer				
No. of individuals (ha^{-1})	-	10 - 50	200 - 250	400 - 500
% of basal area	-	3	15	75
Biomass (t ha^{-1})	>400	300	200	100

Trees of above 10cm dbh.
Sources: Kartawinata *et al.* (1981a,b), Mori (2000), Proctor *et al.* (1983), Sukardjo *et al.* (1990), Sist and Saridan (1998), Toma *et al.* (2000), and Yamakura *et al.* (1986).

Figure 1. Schematic model of forest degradation and recovery



Thick arrow is degradation by forest fires (straight line) and logging (dotted line). Thin arrow (R) is forest recovery for 15 years from 1983 to 1997.
Forest types, A: Undisturbed or lightly disturbed dipterocarp forest (P of D1 in Table 1), B: Forest dominated by dipterocarps in basal area but not in number of individuals (D2 in Table 1), C: Forest dominated by non-dipterocarp primary species, D: Pioneer species dominate (M in Table 1) or fallowlands after slash-and-burnt agriculture, E: Shrub forest with fire tolerant and early succession species. SL: Selective logging . F: Forest fire.

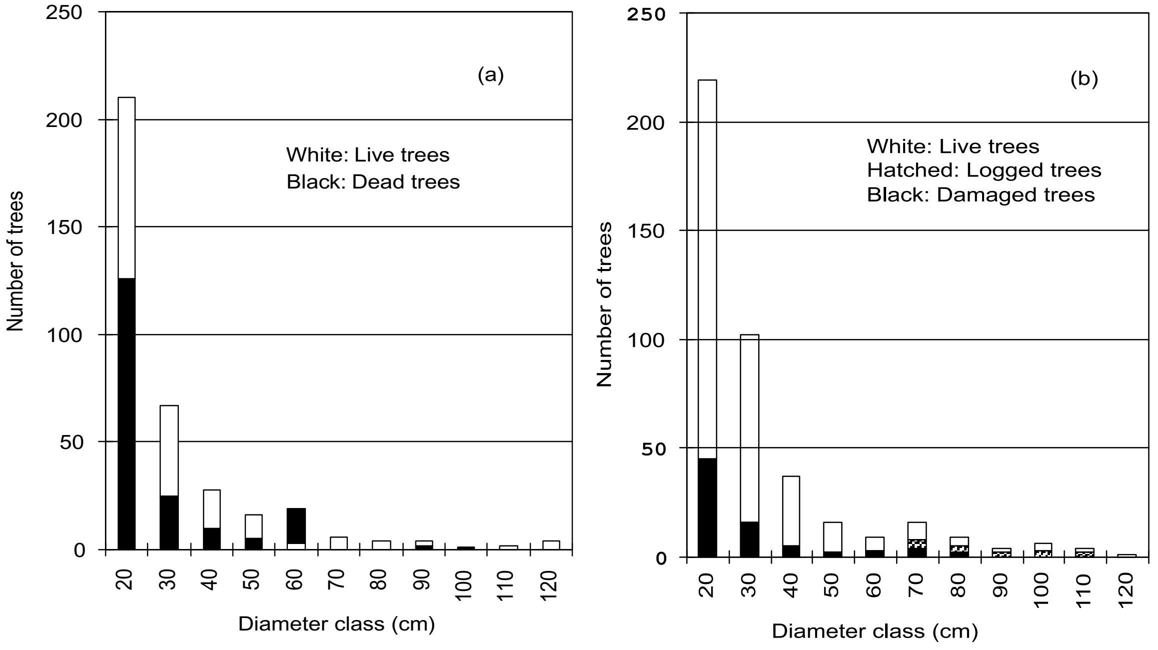
Commercial selective logging and surface fires affect diameter distribution differently (Fig. 2). Selective logging generally harvests trees more than 50 cm dbh. Felling and skidding damages a high percentage of small diameter trees (Ruslim *et al.* 2000, Okimori and Matius 2000a). On the other hand, surface fire mainly kills small diameter trees, especially seedlings and saplings (Toma *et al.* 2000). In general, fire reduces the number of small diameter trees more than logging and results in a lack of successful trees for the next generation. Furthermore, in 1997-98 even emergent trees on the ridges were killed by the combination of drought and fire (Kiyono and Hastaniah 2000). Degradation of burned forest is much more severe than forests logged by the conventional method (Indonesian Selective Cutting and Planting System). So if there is no intervention with rehabilitation treatments, there will be further degradation of the forests and recovery of burned forest will take a very long time.

Shrub forest occurs frequently near roads and appears to be fallow land or abandoned farmland (Kiyono and Hastaniah 1997, Okimori and Matius 2000b). It consists of sprouts of fire-tolerant tree species and pyrophytic species because it is often burned by wildfire. Typical sprouting species are *Nauclea, Millettia, Schima* (Mori 2000). Tree species that recover after fire are mostly early succession species such as *Trema cannavina, Macaranga tanarius* and *Piper aduncum.* It is very difficult for shrub forest to return to original forest without rehabilitation because of lack of mother trees of primary species. This site may become *Imperata* grassland if seeds of early succession trees are deficient in the soil.

REHABILITATION METHODS

This report is focused on dipterocarp forest restoration because it is important economically and also biologically and environmentally. Furthermore, the silvicutural techniques of fast-growing trees, such as *Acacia, Eucalyptus, Paraserianthes, Gmelina* and *Peronema* species

Figure 2. Number of live, logged and damaged trees per ha by (a) surface fire and (b) logging at each diameter class



Diameter class 20 represents 10-20 cm, class 30 is 20-30 and so on.
Sources: Toma *et al.* (2000) and Okimori and Matius (2000)

have already been determined and commercial trees, such as *Pinus, Tectona, Swietenia* species have been used as plantation species. However, techniques for dipterocarps, which are representative of Southeast Asian timber trees, are not fully developed except for a few fast-growing species, such as *Shorea leprosula* and *S. robusta*.

Lightly Degraded Forest

Burned forest rarely has pole-sized trees, saplings and seedlings except for a few fire-tolerant species. Ulin (*Eusideroxylon zawgeri*) is strongly fire-tolerant, its pole-sized and mature trees sprout readily, but its seedlings and saplings are killed by fire (Hastaniah and Kiyono 2000). In forests where primary tree species such as dipterocarps and ulin are still dominant (e.g., D1 in Table 1), natural regeneration is the cheapest way to recover original forest, although it needs follow-up tending. Mass flowering of dipterocarps occurred three times during the 1990s in Bukit Soeharto Forest (Kiyono and Hastaniah 2000) and this site may have the chance of natural regeneration on average two or three times every 10 years.

Many factors effect the survival and establishment of seeds and seedlings. Ashton (1998) gives three stages of establishment and growth of successor trees: (1) seed requires partial shade protection for germination and early survival, (2) seedlings require an increase in light for satisfactory establishment and growth, (3) seedling survival and establishment is usually site specific, according to particular biotic, microclimatic and edaphic characteristics. The factors effecting seed germination and seedling growth fluctuate spatially and yearly and also influence each species differently. Thus if seedlings of many species occur on the forest floor, some of them will pass through the critical conditions caused by micro-climatic and/or biotic fluctuations. But, if there are few species, their survival may be very low. Edaphic specificity of the species mainly influences growth of saplings and pole-sized trees.

The site specificity of a single dipterocarp species is relatively narrow. For example, in Brunei 60 dipterocarp species occur only on one soil type, 65 species on 2 soil types, 12 species on 3 soil types, and only 7 species on 4 soil types (Jacobs 1981). However, about 270 species of the family Dipterocarpaceae grow at various sites in Borneo and physiological and ecological characteristics should differ widely. Therefore, a group of dipterocarps almost completely dominates a stand in the humid tropics, although a single species rarely cover a wide area, with the exception of species such as *Dryobalanops aromatica* and *Shorea robusta*. If there are many dipterocarp species mixed in a stand, there is a high probability of successful natural regeneration, but if the site has only a few dipterocarp species natural regeneration may be very difficult.

Follow-up tending after seedling establishment is very important. The most critical treatment is improvement of light conditions of the seedlings and saplings by release cutting or canopy opening because light deficiency is the main factor causing death after the establishment of seedlings. Until sapling stage, top canopy opening is unnecessary because the light requirement of small trees is generally low, but when trees become pole-size, top canopy opening is necessary. The following prescription may be helpful in practice: 80% (relative light intensity) for pole-sized trees, 50% for saplings, 30% for seedlings and less than 10% for seed germination. Furthermore, the treatment stage (year) should change according to the species' light requirement level. For example, relatively light demanding species such as *Shorea leprosula, S. parvifolia* and *Hopea odorata,* must be allowed more light at the early stage. Consequently, we should determine light requirement levels of major primary forest species.

Moderately Degraded Forest

This forest has large gaps (e.g., D1 or D2 in Table 1) which are generally occupied by pioneer tree species of Euphorbiaceae (*Macaranga, Mallotus, Homalanthus, Glochidion* etc.) (Toma *et al*. 1997). In nature, pioneer trees begin natural thinning after about 10 years of age and late secondary species or sometimes early primary species develop under them. Enrichment planting is often needed to promote this process, especially in the burned forest where there are few successor trees. Thus patch (gap) planting or underplanting in large gaps is appropriate for rehabilitation.

Patch planting is preferred when sufficient planting stock of relatively light-demanding primary species, such as *S. leprosula, S. parvifolia* and *Hopea odorata,* is available. It is recommended that the planting area diameter is equal to the average height of surrounding trees. When pioneer species start to decline in growth, more than about 15 years old, underplanting is preferred for many dipterocarps. Selection of species suited to the local soil and site conditions is essential for both types of planting. When planting stock of suitable dipterocarp species is not available, it is recommended that no action be taken or more widely adaptable species, e.g. *Peronema canescens*, planted. In the hill or mountain areas, many patches may be occupied by the different species according to the soil conditions. It is not recommended that a stand of a single species be made. Mixed species forest is natural and has strong resistance to many insects and diseases (Mardji 2000). Mixed forest is also preferable environmentally. In addition to gap planting, natural regeneration may be expected if there are plenty of pre-existing wildlings in this moderately degraded forest.

Heavily Degraded Forest

Heavily degraded forest has only a few primary species (e.g., M in Table 1) and should be rehabilitated by planting. The rationale is described in natural regeneration of the forest. If the dominated pioneer trees are a decline phase of their growth cycle, underplanting is preferable. In the growing phase, patch planting or line planting is recommended. Choice of edaphically unsuited species and light deficiency after seedling establishment due to lack of follow-up tending are the two major reasons for failure in patch planting or line planting.

For this type of forest, a sliding strip planting (modified line planting) is proposed. The width of cutting strip is half to one fifth of the surrounding tree height. The strip width changes depending on the light requirements of the species planted. Distance between strips is average tree height of the forest or 3-4 times strip width. Weidelt (1996) suggested that in line enrichment planting, a buffer zone both sides of planting corridor (2-3 m) is desirable. After 4-5 years of weeding, the strip is expanded to introduce more light. This area becomes the next planting strip (Fig. 3). A third strip is made on the side opposite the second strip. Thus, after 3 to 5 cycles of strip planting the entire area is planted with different-aged trees. It is preferable to plant more light-demanding species later in the cycle. The standard planting examples are shown in Fig. 3.

Grassland or Shrub Forest

This type of area should be reforested initially by fast-growing tree species or commercial timber species such as teak, mahogany, pine, etc. If dipterocarp species are planted directly, light-demanding and drought-tolerant species should be selected. *Shorea leprosula* and *Hopea odorata* are good candidates for planting open land. However, underplanting or line planting of dipterocarps after establishment of fast growing trees is generally safer and recommended.

Underplanting trials of dipterocarps in *Acacia mangium* stands showed that the seedling growth was the best for the first few years where one or two rows were removed (7-9 m opening) (JICA 1994). Subsequently, trees planted in a wider opening (18 m) had the highest growth. These results suggest that the sliding strip planting as described above is adaptable to the line planting of dipterocarps in plantation forest. On the other hand, a combination of fast growing tree species and selected dipterocarp species are recommended on the basis of reforestation experiments with dipterocarp species on grassland in South

Figure 3. Model of sliding strip planting

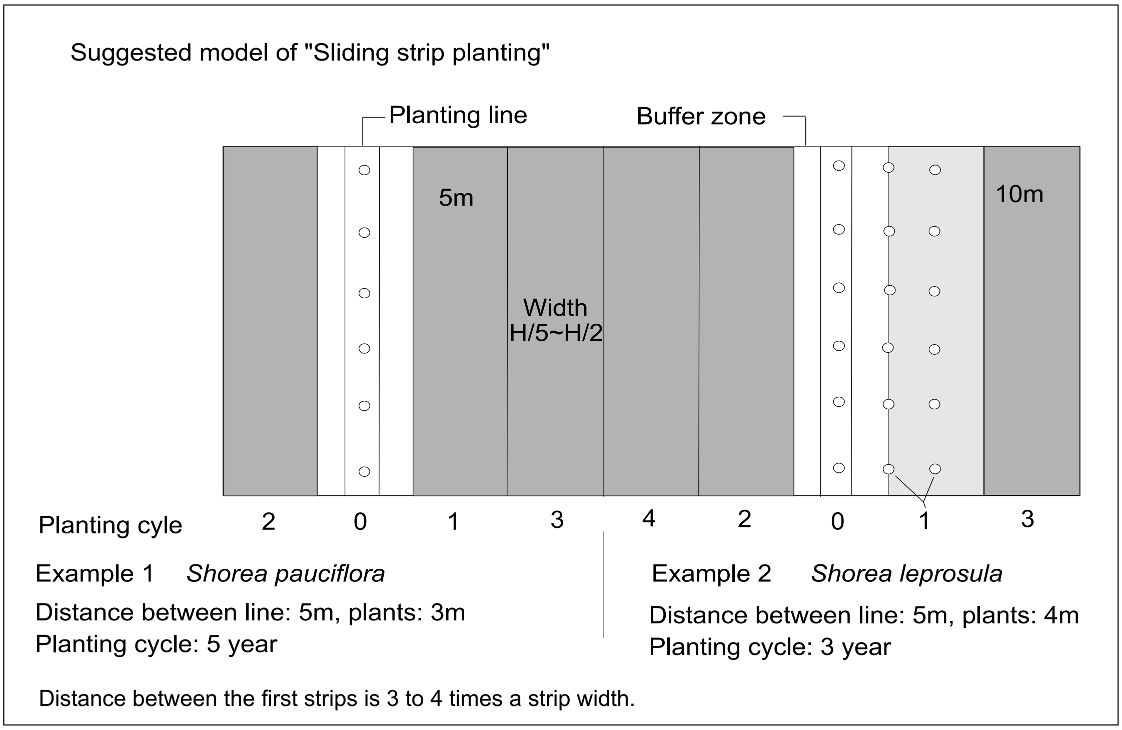


Table 2. Dipterocarps recommended for planting in Malaysia and Indonesia

For enrichment planting in Peninsula Malaysia		For combination planting on grassland in Indonesia
Species		Species
Anisoptera laevis	*Hopea odorata*	*Anisoptera marginata*
A. scalphuta	*Shorea acuminata*	*Hopea sangal*
Dipterocarpus baudii	*S. leprosula*	*Shorea leprosula*
D. costulatus	*S. macroptera*	*Vatica* sp.
D. kerrii	*S. ovalis*	
Dryobalanops aromatica	*S. parvifolia*	
D. oblongifolia	*S. platyclados*	

Sources: Ishida *et al.*(2000) and Mori *et al.* (1990).

Kalimantan (Otsamo *et al*. 1996). Table 2 shows a recommended species for grassland planting in Indonesia (Otsamo *et al*. 1996) and proposed species for enrichment planting in Peninsular Malaysia (Appanah and Weinland 1996). In experiments on line and patch planting in shrub forest at Sebule Experimental Site, East Kalimantan, three years after planting *Shorea leprosula* had the highest survival and growth rate in a wider lines (20 m) or open land and *Shorea pauciflora* had better growth under a *Macaranga* sp. canopy and narrower lines (6 m). The results show the importance of species selection (Soda *et al*. 1999).

Choice of Planting Species

Tree species planted on a large scale generally can quickly form a pure community of a single species on bare ground, they regularly produce a large amount of seeds and have a short life span. They also have plasticity for edaphic, microclimatic and biotic conditions. Many fast-growing and commercial tree species used now for forest plantations have these characteristics. On the other hand, many dipterocarps have the opposite characteristics: irregular fruiting, shade-demanding, slow-growing in the early growth stages and a long life span, although among the climax tree species, the dipterocarps have relatively rapid diameter growth and high light demand during their middle to mature stages.

Light requirements differ among dipterocarp species. For example, net photosynthetic rate (NPR) varies widely from a level similar to fast-growing species (*S. leprosula*) to that of undergrowth plants (*Neobalanocarpus heimii*) (Ishida, *et al.* 2000, Table 3). Variation similar to NPR has been reported for water deficit tolerance, transplanting stress and sprouting capacity of dipterocarp species (Mori 1980, Mori *et al*. 1990, Ito *et al*. 2000). Many dipterocarps require mild environmental conditions in their early growth stages because more than half of the species inhabit humid rain forest that has a narrow range of temperature and humidity fluctuations and the young trees live in partially shaded conditions throughout the year. However, some dipterocarps grow in monsoon forest (e.g., *Dipterocarpus alatus, Hopea odorata*) and dry tropical forest (e.g., *Shorea robusta* in India). These species experience a wide range of climatic changes and have greater tolerance or higher level of plasticity in their growth responses (Mori 1980, Mori *et al.* 1990). Among proposed species for enrichment planting by the Forest Research Institute Malaysia (FRIM) in Table 2 one third (5 species) occur in monsoon forests. In addition to these species, the species growing at the forest margin, e.g., *Shorea leprosula*, also experience relatively strong climatic stress and are candidates for planting in open areas. Table 4 shows the basic criteria on which choice of species for planting can be based.

Table 3. Comparison of maximum net photosynthetic rate among fast and late growing species

	Area basis µmole $m^{-2}s^{-1}$	Mass basis µmole $kg^{-1}s^{-1}$
Fast growing species		
Acacia auriculiformis	12.0	
Macaranga gigantea		
Large gap site	8.1	155
Small gap site	4.5	112
Dipterocarp species		
Shorea leprosula		
(fast-growing dipterocarp)		
Large gap site	11.0	103
Small gap site	5.4	64
Shorea parvifolia	5.5	
Dryobalanops aromatica	3.8	
Neobalanocarpus heimii		
(slow-growing dipterocarp)		
Large gap site	1.9	23
Small gap site	3.5	46

Sources: Ishida *et al.*(2000) and Mori *et al.* (1990).

Table 4. Criteria for choice of planting species

Features	Prefered characteristics
Growth	
Diameter growth	Continue to late stage
Height growth	Vigorous in young stage
Reproduction	
Seed production	Regular fruiting
Vegetative propagation	Easy if possible
Species specificity	
Site (edaphic) specificity	Low if possible or well-known
Plasticity for environments in seedling stage	High level for light, temperature, and soil water deficit
Pest and disease specificity	Low epidemicity
Utilisation	
Stem shape	Straight and round
Rotation	Relatively short (60-70 years)

Modified from Appanah and Weinland (1996).

CONCLUDING REMARKS

The key technology for rehabilitation using dipterocarp species is light control and species choice. Light control should correspond to the light requirements of a species and also to its growing stages. Pre-existing trees or fast-growing trees should be effectively utilised for light control. The irregularity of seed production in dipterocarps can influence the choice of species for planting. If suitable dipterocarp planting stock adapted to a planting site is not available it is better to postpone planting or initially plant commercial species with wide adaptability. Establishing stands of a single dipterocarp species is not recommended. To promote mixed planting with other climax species and to compensate irregular seed production of dipterocarps, much more study is needed to clarify relationships among dipterocarp species and other climax species. There is a particular need to clarify species' specificity from the viewpoint of their whole plant seedling physiology and ecology because our knowledge is still fragmented and poor compared with many commercial timber species in cultivation.

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3

Fire Resistance of Tree Species in Bukit Soeharto Education Forest, East Kalimantan, Indonesia

A. Delmy[1]

Abstract

The effects of the forest fire on anatomical and ecophysiological resistance of tree species was investigated in Bukit Soeharto Education Forest, an area about 5000 ha, in East Kalimantan, Indonesia. The forest was impacted seriously by forest fire in 1998. This forest land is dominated by Dipterocarpaceae species, especially *Shorea* spp., with some *Dryobalanops, Cotylelobium* and *Anisoptera* species. The investigation was conducted in a single plot of burned primary forest with scattered gaps. The gaps had mixed pioneer and non-pioneer species, such as *Eusideroxylon zwageri, Macaranga hypoleuca, Shorea laevis, Macaranga gigantea, Palaquium rostratum* and *Polyalthia sumatrana.* Tree density (>10 cm diameter) was 337 ha^{-1}. After the forest fire there were 147 dead trees ha^{-1} mainly *Macaranga hypoleuca, Macaranga gigantea, Shorea laevis, Palaquium rostatum, Polyalthis sumatrana* and *Hydnocarpus polypetala.* There were 41 sprouted tree species ha^{-1}, mainly *Eusideroxylon zwageri, Litsea* sp*., Durio carinatus, Gironniera nervosa* and *Diospyros curaniopsis.* There were 151 living, but unsprouted, trees ha^{-1} dominated by *Eusideroxylon zwageri, Shorea laevis, Shorea palembanica, Palaquium macrophyllum* and *Shorea smithiana,* The numbers of dead and sprouting trees were related to the fire conditions and only some tree species had sprouts. Bark thickness was positively correlated with fire resistance and the healthiness of the trees in the canopy.

INTRODUCTION

Mulawarman University Education Forest at Bukit Soeharto, East Kalimantan is protection forest and well-reserved tropical rain forest dominated by many Dipterocarpaceae species. For more than 8 months during 1982-1983 and 1997-1998 it was exposed to extreme desiccation and a large area was burnt. In 1982, 3.1 million ha of forest was burned in East Kalimantan and in 1998 fire damaged 5.5 million ha. The pattern of forest damage and destruction is different from place to place. Climate, weather, and vegetation all influence the pattern of burning. Forest fire has seriously reduced the quality of the forest from ecological and economical points of view. One serious effect is that most trees in the early growing stages are burned. Tree species having ≥10 cm diameter at breast height have different fire resistance related to anatomical and ecophysiological features.

This study aimed to (1) recognise tree species surviving fire, (2) identify species remaining alive by producing sprouts, and (3) determine the dominance of tree species surviving by producing sprouts.

METHODS

Site Description

The research area is in Mulawarman University Education Forest, which lies between 0°50' - 1°01' S latitude and between 115°36' - 116°54' E longitude, 60 km south of Samarinda, East Kalimantan, Indonesia. The Education Forest is part of Bukit Soeharto Protection Forest and has an area of 5000 ha. The research sample plots

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have an area of 1.2 ha (100 m x 120 m) in primary forest burnt in the 1998 fire. Soil type is mainly red yellow podsolic originating from sedimentary rocks and non-volcanic sediments. It is 60-120 m above sea level with undulating topography and moderate to steep slopes ranging from 20° to 45° (Anon. 1987). The climate is type A with Q value 13.04% in the classification of Schmidt and Ferguson (1951). Mean annual rainfall is 2270 mm with the monthly mean 164 mm without any dry months. Daily average relative humidity is 83% with a range 81-86%. Daily average temperature is 27.2°C. Wind direction varies seasonally and daily with the average velocity in the range 40-70 km hour^{-1}.

The vegetation is typical Southeast Asian tropical rain forest dominated by Dipterocarpaceae species, especially the genera *Shorea, Dipterocarpus, Anisoptera, Dryobalanops*, and *Cotylelobium.* The Dipterocarpaceae family is followed by Lauraceae, Euphorbiaceae, Sapotaceae, Myristicaceae, Ebenaceae, Burseraceae, Moraceae and Annonaceae in order of dominance (Okimori and Matius 1991). The dominance order of species is: *Eusideroxylon zwageri, Shorea laevis, Mallotus echinatus, Dipterocarpus cornutus, Palaquium gutta* and *Diospyros curaniopsis.*

Field Survey

Diameter was measured for all individuals having ≥10 cm diameter (bh), or at 20 cm above the buttress line. Trees were identified in the Dendrology Laboratory, Faculty of Forestry. Fire effects were determined by the height and depth of fire injuries on the trunk. Bark thickness was measured on tree species with sprouts produced after the fire and Canopy condition was determined based on the amount of green leaves in a whole canopy and expressed as a percentage.

RESULTS AND DISCUSSION

The main reasons that the Education Forest has not escaped fire damage are the long drought period, it is adjacent to areas where villagers actively practise slash and burn agriculture, and charcoal production within and surrounding the forest. As a result, the Education Forest is not primary virgin forest but seriously degraded primary and/or secondary forest with many gaps (Table 1).

Table 1. Importance rating of the main species before the fire

Species	F[1]	N	BA (m^2)	FR (%)	DR (%)	DoR (%)	IV (%)
Eusideroxylon zwageri	22	44	5.00	14.6	10.96	17.2	42.6
Macaranga hypoleuca	18	36	1.38	11.9	8.9	4.7	25.5
Shorea laevis	8	16	3.61	5.0	4.0	12.4	21.3
Macaranga gigantea	12	22	0.66	7.3	5.4	2.3	15.0
Palaquium rostratum	13	18	0.53	5.6	4.4	1.8	11.9
Polyalthia sumatrana	9	15	0.43	5.0	3.7	1.5	10.1
Shorea smithiana	4	5	2.15	1.3	1.3	7.4	10.0
Palaquium macrophyllum	7	11	0.60	3.3	2.7	2.1	8.1
Shorea ovalis	4	6	0.90	1.7	1.5	3.1	6.2
Eugenia sp.	5	8	0.45	2.7	2.0	1.6	6.2
Dacryodes rostrata	8	8	0.26	2.7	2.0	0.9	5.6
Litsea sp.	6	6	0.55	2.0	1.5	1.9	5.4
Dialium annuum	6	7	0.34	2.3	1.8	1.2	5.3
Hydnocarpus polypetala	6	8	0.15	2.7	2.0	0.5	5.1
Gluta wallichii	5	6	0.27	1.7	1.5	0.9	4.1
Shorea lamellata	3	3	0.67	1.0	0.8	2.3	4.1
Diospyros curaniopsis	5	6	0.19	1.7	1.5	0.7	3.8
Shorea parvifolia	2	3	0.69	0.7	0.8	2.4	3.8
Shorea leprosula	4	4	0.43	1.3	1.0	1.5	3.8
Eugenia sibulaneensis	3	4	0.48	1.0	1.0	1.7	3.6

[1] F (frequency); N (number of individuals); BA (basal area); FR (relative frequency); DR (relative density); DoR (relative dominance); IV (importance value)

Of the 20 dominant species before the forest was burnt in 1998 (Table 1), two pioneer species, *Macaranga hypoleuca* and *Macaranga gigantea*, were very common after *Eusideroxylon zwageri* and *Shorea laevis*. Other non-pioneer species are very common in primary forest. *Macaranga hypoleuca and Macaranga gigantea* are often found gregariously in gaps where they grow fast and form homogenous stands. In Kutai National Park, *Macaranga gigantea* is a major species in secondary forest along the sides of logging roads (Tagawa 1988). Bratawinata (1988) made a similar observation in Bukit Soeharto Forest Reserve and Whitmore (1975) found stands of *Macaranga gigantea* in open areas at Sungai Kroh, Malaysia. A high proportion of buried seeds are pioneer species, including *Macaranga* spp., that remain dormant in the forest floor at a depth of 15 cm (Delmy 1996).

The non-pioneer tree species in Table 1 are commonly found in climax primary forest, some of them are emergents such as *Shorea laevis, S.smithiana, S. ovalis, S. lamellata, S. parvifolia* and *Dialium annuum.* According to the historical information, Bukit Soeharto Forest Reserve was once logged in the 1970s. This plot area seems to have been left unlogged because of very steep topography, so many emergent trees remain.

The forest fire killed most pioneer species, particularly *Macaranga* spp. (Table 2). Three species, *Macaranga hypoleuca*, *M. gigantea* and *M. triloba* could not tolerate to heat of the fire although their bark was not burnt. Their bark is smooth and thin (2-3 mm) so heat can penetrate easily. Trunk bark thickness, fire heat intensity and exposure time are factors influencing the extent of damage. For example, trunk bark thickness of primary species varied very widely, from 2-13 mm. Despite having bark thickness of 13 mm, *Shorea leprosula* and *Shorea parvifolia* were killed and it may be assumed the fire was more severe or the exposure time longer. The structure of outer bark, inner bark and cambium differs among species and varies with age (Bratawinata 1995). The relationship between diameter classes and death rates of individual trees shows a lower death rate the higher the diameter class (Table 3). Tree with a bark thickness ranging from 1-5 mm were more often killed than those with thicker bark (Table 4).

Table 2. Importance rating of dead tree species after the fire

Species	F[1]	N	BA (m^2)	FR (%)	DR (%)	DoR (%)	IV (%)
Macaranga hypoleuca	15	35	1.26	11.4	19.6	15.0	45.9
Macaranga gigantea	12	22	0.66	9.1	12.3	7.9	29.3
Shorea laevis	5	8	1.44	3.8	4.5	17.1	25.4
Palaquium rostratum	11	14	0.35	8.3	10.6	4.2	23.1
Polyalthia sumatrana	9	13	0.35	6.8	7.3	4.2	18.3
Hydnocarpus polypetala	6	7	0.14	4.6	3.9	1.6	10.1
Shorea parvifolia	1	1	0.68	0.8	0.6	8.1	9.4
Shorea smithiana	2	2	0.53	1.5	1.1	6.3	8.9
Shorea leprosula	3	3	0.36	2.3	1.7	4.3	8.2
Dialiun annuum	1	6	0.34	0.8	3.4	4.1	8.2
Dacryodes rostrata	5	5	0.09	3.8	2.8	1.1	7.7
Macaranga triloba	4	4	0.13	3.0	2.2	1.5	6.8
Artocarpus elasticus	2	3	0.17	1.5	1.7	2.1	5.3
Litsea sp.	3	3	0.09	2.3	1.7	1.1	5.0
Shorea ovalis	3	3	0.08	2.3	1.7	1.0	4.9
Pternandra azurea	3	3	0.06	2.3	1.7	0.7	4.6
Polyalthia glauca	3	3	0.05	2.3	1.7	0.7	4.6
Eugenia sp.	2	2	0.13	1.5	1.1	1.6	4.2
Hopea mengarawan	2	2	0.10	1.5	1.1	1.1	3.8
Aporusa sp.	2	2	0.09	1.5	1.1	1.0	3.7

[1] F (frequency); N (number of individuals); BA (basal area); FR (relative frequency); DR (relative density); DoR (relative dominance); IV (importance value)

Table 3. Relationship between diameter class and tree condition

Diameter class (cm)	Dead trees	Sprouted trees	Living trees, no sprouts	Total number of trees
		(%)		
10-19	54.5	9.9	35.5	211
20-29	42.8	10.1	47.3	89
>30	21.9	18.1	60.0	105
Mean	43.5	12.1	44.4	405

Table 4. Number of dead trees in different diameter and bark classes

Diameter class (cm)	1-<2	2-<3	3-< 4	4-<5	5-<6	6-<7	>7	Total
10 - 19	4	29	57	24	-	-	1	115
20 - 29	-	14	6	7	3	3	5	38
> 30	-	-	5	9	1	1	7	23
Total	4	43	68	40	4	4	13	176

Tree species that survived with and without sprouts are shown in Tables 5 and 6. A sprout is a new shoot which emerges laterally from the trunk. Sprouts will generally appear if the plant suffers severe disturbance its growth, e.g. damage by forest fire or logging operations. Only certain tree species can produce sprouts naturally, and it seems to depend on the degree of disturbance. Among 20 sprouted tree species, *Eusideroxylon zwageri* was prominent followed by *Litsea* sp., *Durio carinatus, Gironniera nervosa,* and *Diospyros curaniopsis*. *Eusideroxylon zwageri* produces sprouts easily and no dead trees were found. It can also produce about 10-20 sprouts on each tree and these sprouts drop when stem diameter reaches 20 cm (Beekman 1949). As shown in Tables 6 and 7, *Eusideroxylon zwageri* was also prominent among the tree species that survived without sprouts. It is clear that only some tree species can produce sprouts and sprouting is very dependent on environmental factors such as degree of damage, humidity and temperature (Bratawinata 1995).

Eusideroxylon zwageri is present in all diameter classes with and without sprouts. Other tree species are not as consistent e.g. *Diospyros borneensis, D. curaniopsis,* and *Eugenia* sp., are present in all diameter classes without sprouts and present with sprouts in <30 cm diameter classes. Other species, such as *Artocarpus anisophyllus, Cryptocaria crassinervis. Dacryodes rostrata, Durio carinatus, Endiandra* sp., *Gironniera nervosa* and *Litsea costalis*, have sprouts mainly in >30 cm diameter classes. Those with sprouts only in <20 cm diameter classes are: *Diospyros borneensis, Eugenia* sp., *Elatriospermum tapoz, Macaranga hypoleuca, Nephelium eriopetalum, Polyalthia sumatrana, Pentace laxiflora, Palaquium rostratum* and *Scorodocarpus borneensis.* This situation suggests that occurrence of sprouts is randomly affected by diameter classes.

Sprouting trees cluster in the medium bark thickness (2-6 mm) class and few trees have very thick bark (Table 8). There are less sprouted trees in diameter class (20-<30 cm) than in classes (10-<20 cm) and (>30 cm). This indicates that there is no correlation between diameter and bark thickness (Table 9). It appears that many of non-sprouted tree species survived in high bark thickness classes. It is therefore not possible to classify fire resistance only on the basis of stem diameter and bark thickness. In burnt forest areas most of the canopy was changed drastically by drying out of some branches or the whole crown in dead trees. The relationship between a healthy canopy condition and the number of individuals of sprouted and non-sprouted trees is shown in Tables 10 and 11.

The distribution of sprouted individuals trees varies randomly among the three diameter classes. Sprouted trees are found in relatively large numbers in poor canopy (80% of the total) whereas non-sprouted tree species occur where there is a healthy canopy.

Table 5. Importance value of sprouted tree species after forest fire

Species	F[1]	N	BA (m^2)	FR (%)	DR (%)	DoR (%)	IV (%)
Eusideroxylon zwageri	13	20	2.71	31.7	41.7	63.4	136.8
Litsea sp.	2	2	0.28	4.9	4.2	6.6	15.7
Durio carinatus	2	1	0.19	4.9	2.1	4.5	11.5
Gironniera nervosa	2	2	0.10	4.9	4.2	2.4	11.5
Diospyros curaniopsis	2	2	0.03	4.9	4.2	0.81	9.9
Palaquium rostratum	2	2	0.03	4.9	4.2	0.78	9.8
Durio griffithii	1	2	0.14	2.4	4.2	3.2	9.8
Dacryodes rostrata	1	1	0.11	2.4	2.1	2.7	7.2
Litsea costalis	1	1	0.10	2.4	2.1	2.3	6.8
Endiandra sp.	1	1	0.09	2.4	2.1	2.0	6.5
Artocarpus anisophyllus	1	1	0.08	2.4	2.1	1.9	6.4
Pometia pinnata	1	1	0.06	2.4	2.1	1.4	6.0
Sarcotheca sp.	1	1	0.05	2.4	2.1	1.2	5.8
Palaquium hexandrum	1	1	0.04	2.4	2.1	0.97	5.5
Diospyros borneensis	1	1	0.03	2.4	2.1	0.67	5.2
Elatriospermum tapoz	1	1	0.03	2.4	2.1	0.60	5.1
Cryptocaria crassinervis	1	1	0.02	2.4	2.1	0.53	5.1
Macaranga hypoleuca	1	1	0.02	2.4	2.1	0.47	5.0
Nephelium eriopetalum	1	1	0.02	2.4	2.1	0.47	5.0
Polyalthia sumatrana	1	1	0.02	2.4	2.1	0.47	5.0

[1] F (frequency); N (number of individuals); BA (basal area); FR (relative frequency); DR (relative density); DoR (relative dominance); IV (importance value)

Table 6. Importance value of surviving tree species without sprouts after forest fire

Species	F[1]	N	BA (m^2)	FR (%)	DR (%)	DoR (%)	IV (%)
Eusideroxylon zwageri	16	24	2.28	10.6	13.9	13.1	37.6
Shorea laevis	3	7	2.42	2.0	4.1	13.9	19.9
Shorea palembanica	1	1	2.42	0.7	0.6	13.9	15.1
Palaquium macrophyllum	7	10	0.60	4.6	5.8	3.5	13.9
Shorea smithiana	2	2	1.60	1.3	1.2	9.2	11.7
Diospyros curaniopsis	5	5	0.19	3.3	2.9	1.1	7.3
Diospyros borneensis	4	5	0.25	2.7	2.9	1.4	7.0
Gluta walichii	4	4	0.23	2.7	2.3	1.4	6.3
Palaquium rostratum	4	4	0.18	2.7	2.3	1.0	6.0
Myristica sp.	4	4	0.11	2.7	2.3	0.6	5.6
Eugenia sp.	2	4	0.30	1.3	2.3	1.7	5.3
Shorea leptoclados	1	1	0.64	0.7	0.6	3.7	4.9
Eugenia surangarianum	3	3	0.12	2.0	1.7	0.7	4.4
Neesia sp.	2	3	0.23	1.3	1.7	1.3	4.4
Knema linifolia	3	3	0.11	2.0	1.7	0.6	4.4
Dillenia grandifolia	1	1	0.43	0.7	0.6	2.5	3.7
Garcinia macrophylla	2	2	0.19	1.3	1.2	1.1	3.6
Diospyros macrophylla	2	3	0.09	1.3	1.7	0.5	3.6
Drypetes neglecta	2	2	0.16	1.3	1.2	0.9	3.4
Artocarpus elasticus	2	2	0.150	1.3	1.2	0.9	3.3

[1] F (frequency); N (number of individuals); BA (basal area); FR (relative frequency); DR (relative density); DoR (relative dominance); IV (importance value)

Table 7. Species with and without sprouts according to diameter classes

Species	[1]Species present with and without sprouts according to diameter classes (cm)		
	10-<20	20-<30	>30
Artocarpus anisophyllus	*	-	+
Cryptocaria crassinervis	*	-	+
Durio griffithii	+	*	+
Dacryodes rostrata	*	-	+
Durio carinatus	-	-	+
Endiandra sp.	*	-	+
Gironniera nervosa	*	-	+
Litsea costalis	-	-	+
Diospros borneensis	+/*	*	*
Diospyros curaniopsis	*	+/*	*
Eusideroxylon zwageri	+/*	+/*	+/*
Litsea sp.	-	+	+/*
Knema linifolia	*	+/*	-
Pometia pinnata	-	+	-
Sarcotheca sp.	-	+	*
Palaquium hexandrum	-	+	-
Eugenia sp.	+/*	*	*
Elatriospermum tapoz	+/*	-	-
Macaranga hypoleuca	+	-	*
Nephelium eriopetalum	+	-	-
Poplyalthia sumatrana	+/*	*	-
Pentace laxiflora	+	-	-
Palaquium rostratum	+/*	-	*
Scorodocarpus borneensis	+/*	-	*

[1] (+) present with sprouts (*) present without sprouts (-) absent

Table 8. Number of trees in different diameter and bark thickness classes in sprouted trees

Diameter class (cm)	Bark thickness class (mm)							
	1 - < 2	2 - <3	3 - < 4	4 - <5	5 - <6	6 - < 7	> 7	Total
10-< 20	-	4	11	3	1	-	2	21
20-< 30	-	1	2	2	3	-	1	9
> 30	-	-	3	4	7	-	5	19
Total	-	5	16	9	11	-	8	49

Table 9. Number of trees in different diameter and bark thickness classes in trees surviving without sprouts

Diameter class (cm)	Bark thickness class (mm)							
	1 - < 2	2 - <3	3 - < 4	4 - <5	5 - <6	6 - < 7	> 7	Total
10-<20	-	5	28	20	7	5	10	75
20-<30	-	1	5	5	9	9	13	42
>30	-	-	9	3	8	9	34	63
Total	-	6	42	28	24	23	57	180

Table 10. Number of sprouted tree species and canopy health and stem diameter classes

Diameter class (cm)	Canopy health class (%)				
	0 - <25	25 - <50	50 - <75	75 - 100	Total
10-< 20	8	5	1	7	21
20-< 30	4	2	-	3	9
> 30	2	-	4	13	19
Total	14	7	5	23	49

Table 11. Number of non-sprouted tree species and canopy health and stem diameter classes

Diameter class (cm)	Canopy health class (%)				
	0 - <25	25 - <50	50 - <75	75 - 100	Total
10-< 20	2	6	10	57	75
20-< 30	1	4	2	35	42
> 30	3	4	4	52	63
Total	6	14	16	144	180

CONCLUSIONS

- Most of pioneer tree species, and some primary tree species, with small stem diameters were killed by the 1998 fire.
- Only certain primary forest species, especially *Eusideroxylon zwageri*, produced sprouts.
- There was no apparent correlation between stem diameter and sprouting, and bark thickness and sprouting so inherent characteristics are largely responsible for the sprouting of certain species.
- Occurrence of dead, sprouted and non-sprouted trees is correlated with the state of health of the tree canopy.
- Occurrence of dead and sprouted trees seemed closely related to fire conditions such as intensity of the fire and/or period of exposure.
- A single factor, such as stem diameter or stem bark thickness, cannot explain the fire resistance of tree species.

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Impact of Logging and Forest Fires on Soil Erosion in Tropical Humid Forest in East Kalimantan

T. Sudarmadji[1]

Abstract

Logging and/or forest fires cause a direct impact of reducing vegetation cover, and in many cases create a pre-condition for the increase of soil erosion rates during high rainfall. Such an increase in soil erosion rate may be higher than the normal threshold rate from a sustainable forest land productivity viewpoint. Field measurement was focused on surface runoff (overland flow) and eroded soil mass on slopes of 25-35% with light and heavy intensities of logging and control plots. Both logging intensities directly increased surface runoff and eroded soil mass, especially on timber felling, skidding trails establishment and log skidding and/or hauling from the logging compartments through feeder roads to the temporary logyard. Higher rainfall amounts and intensity tended to increase the volume of surface runoff and for some cases also eroded soil mass. The volume of surface runoff was 2559 litre ha^{-1} year^{-1}; 4711 litre ha^{-1} year^{-1} and 5123 litre ha^{-1} year^{-1}; while the cumulative eroded soil mass was estimated to be 0.073 t ha^{-1} year^{-1}; 0.046 t ha^{-1} year^{-1}, and 0.060 t ha^{-1} year^{-1} for the light, heavy and control of logging intensities respectively. However, the eroded soil mass in all research plots confirmed that there was no significant relationship between soil erosion rate and logging intensity, and the eroded soil mass was lower than the tolerable/permissible/acceptable soil erosion rate. Therefore, erosion control measures in relation to land productivity after logging and fires do not need to be carried out immediately. Regarding the erosion process, the slope and its length (microtopography) was the most important factor for increasing soil erosion rate. Further, vegetation cover was important in reducing and/or minimising the occurrence of surface runoff and soil erosion.

INTRODUCTION

Background

Forest harvesting can cause unavoidable negative impact to both the biotic and abiotic environment, through damage to residual large trees and other forest plant communities and their natural regeneration, exacerbate surface soil erosion, and change physical soil characteristics. The negative impacts may also appear outside the logged area, e.g. aquatic habitat deterioration, river sedimentation, and degradation of water quality. Each step of logging activities can also cause a range of impacts which may vary in size and duration.

For a long time it has been suggested that there are two kinds of significant change of forest condition related to logging activities i.e., crown cover reduction and forest land compaction due to feeder road construction and temporary and permanent log yards. Reduction of crown cover directly increases the amount of rainfall reaching

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the forest floor and simultaneously reduces rainfall interception. Compaction of forest floor by mechanical log hauling and transportation (tractor, skidder, dozer) creates an increase in surface runoff/overland flow increase as a consequence of reducing infiltration rate and/or its capacities. Under such conditions, the major proportion of rainfall is mostly surface runoff/overland flow because the rainfall intensity is generally much greater than the infiltration capacity. Consequently, the rain drop impact increases the probability of soil detachment and movement. It is also possible that the nutrient cycle of the forest ecosystem will be periodically disturbed by logging activities and their after effects, e.g., soil compaction.

Large-scale forest fires occurred during 1982-1983 in the tropical humid forest areas in Kalimantan causing tremendous damage. Similar forest fires also occurred in 1986, 1991, 1997, and the latest in 1998 which degraded a large forest area and its environment. Ecologically, forest fires caused enormous damage to the vegetation, fauna, soils and aquatic ecosystems. Reduction of vegetation cover and organic material both directly and/or indirectly influence soil characteristics and geomorphic processes due to the loss of soil aggregate stability. Additionally, they increase the probability of greater soil/land erosion. especially in open areas frequently subjected to high rainfall intensity (Sudarmadji 1995).

It is broadly accepted that the most dominant factors affecting soil erosion processes and characteristics are climate (especially rainfall), soil erodibility, topography (length and slope), vegetation cover, erosion control measures, and human activities in land management practice. These factors always interact with each other and simultaneously determine the magnitude of soil erosion rate in a particular landscape (Arsyad 1989).

This study area, Taman Hutan Raya, Bukit Soeharto is representative of tropical humid forest areas with soil erodibility ranging from moderate to high. Using the Universal Soil Loss Equation (USLE), forested area under primary forest, secondary forest, burned forest, *ilalang* land (dominated by *Imperata cylindrica*) and spice plantation, it was found that spice plantation had the highest soil erosion rate. Moreover, Sarminah (1995) using plots of 2.5 m x 20 m in spice plantation, *ilalang* land and logged-over burned forest with 37% of slope found that the potential of soil loss through erosion process was 94.8 t ha^{-1} $year^{-1}$; 2.3 t ha^{-1} $year^{-1}$ and 4.2 t ha^{-1} $year^{-1}$, respectively. In an experiment on degraded land rehabilitation after forest fires on steep slopes (>30%), Sudarmadji (1997) using plots 5 m x 20 m found that degraded lands without any vegetation cover can potentially lose around 18.2 t ha^{-1} $year^{-1}$ of top soil. This large loss could be reduced to 5.8 t ha^{-1} $year^{-1}$ by planting *Peronema canescens*, by applying a layering planting technique by dense planting of cuttings to 6.5 t ha^{-1} $year^{-1}$; while other species with a similar technique reduced the loss to 5.8 t ha^{-1} $year^{-1}$ and 6.7 t ha^{-1} $year^{-1}$.

Problem Formulation

There are two main considerations in relation to increasing soil erosion rate: (1) logging and forest fires reduce the vegetation cover creating a pre-condition for increased surface runoff/overland flow and soil erosion rate where the quantity and intensity of rainfall is high, (2) higher logging intensities and/or forest fires may directly cause soil erosion to increase to a level greater than permissible/acceptable/tolerable in terms of sustainable forest land productivity. Clarification of these problems is important as they are the basis on which decisions are made on erosion control measures and/or degraded land rehabilitation.

Forest Harvesting and Fires

Harvesting of timber is carried out by logging activities which follow the silvicultural system officially applied in Indonesia. In general, the main activities in forest harvesting are felling, hauling and transportation. Construction of feeder roads, branch roads and also main roads are closely related to land degradation, mainly indicated by increased soil erosion rates. Alleviation of this potential damage should be one of the main targets to achieve sustainable forest land productivity and management of forest areas.

Forest fires in East Kalimantan were initiated by a heavy dry period that made the litter on the forest floor very flammable (Hadi 1983). It has been debated for a long time whether slash and burn agriculture is a major cause of fires in East Kalimantan. However, Soedardjo (1982) and Hadi (1983) suggested that forest workers and others carelessly using fire in the forest might also ignite fires. Many burning coal deposits might also start fires in East Kalimantan. Pritchett (1979) and Soeratmo (1979) classified forest fires as: ground fire, surface fire, and crown fire. Forest fire impacts on the chemical characteristics of soil increasing mineral concentration. Additionally, disturbance of the physical soil characteristics will contribute to soil erosion due to soil disaggregation, organic materials destruction, exposing the forest floor to the direct strike of rain and reducing of infiltration capacity (Effendi 1999).

Purpose of the Study

The study’s long-term purpose is to assess the impact of logging and forest fires on soil erosion rates in tropical humid forest areas in East Kalimantan. A part of this study is to determine if the increase of soil erosion rates is above or below the acceptable erosion rate. The results should be an important indicator as to whether erosion control measures and/or land rehabilitation need be carried out during and after logging activities, or after fires in logged over-forest.

Site Description

This research was conducted in Cooperative Research Plots (9 ha) located in Bukit Soeharto Education Forest of Mulawarman University. The 9 x 1 ha plots were established with 3 replications of 3 logging intensities (1) heavy intensity - commercial trees of dbh ≥30 cm were cut, (2) light intensity - commercial trees dbh ≥50 cm cut) and (3) control (no cutting) (Ruslim *et al.* 2000). TAHURA Bukit Soeharto is located at 115° 0’34”-116° 0’054”E and 0° 0’50”-1° 0’04”S at 22-58 m above sea level. The study site is located on a flat plain enclosed by undulating hilly areas with slopes of 25-30% and 5-200 m in length. Annual rainfall is 2002 mm (Toma *et al.* 2000). According to the climate classification system developed by Schmidt and Ferguson (1951), the type of climate is categorised into A type (Q = 12.4%) indicating rainfall distributed throughout the year without a distinct dry period. Mean monthly temperature is 21-27^{0}C with relative humidity 65-90%. In the study site soils are dominated by clay (C), sandy clay (SC), sandy loam (SL) and sandy clay loam (SCL) (Table 1).

Table 1. Soil texture

Solum depth (cm)	Particle fraction content (%)			Texture
	Sand	Silt	Clay	
High intensity				
0-10	68	17	15	SL
10-30	62	17	21	SCL
30-60	47	25	28	SCL
60-100	55	18	27	SCL
Light intensity				
0-10	52	26	22	
10-30	47	24	29	SCL
30-60	41	24	35	SCL
60-100	39	20	41	CL
				C
Control				
0-10	52	22	25	SCL
10-30	48	22	30	SCL
30-60	44	19	37	SC
60-100	21	33	46	C

Source: Effendi (1999)

The latest fires (mid-1997 to 1998) were mainly surface fires which burned over ±80% of the area. However, several dipterocarps resisted forest fires, e.g. *Shorea* sp., *Dipterocarpus* sp., *Dryobalanops* sp., *Eusideroxylon zwageri*, *Dillenia excelsa* and *Diallium indum.* Existing degraded (natural) dipterocarp forest suffered relatively light fire damage and their crowns still shaded the forest floor. Dipterocarp genera/species *Shorea* sp., *Shorea laevis*, *Dipterocarpus* sp., *Dryobalanops* sp. and *Eusideroxylon zwageri* dominate this forest type.

In the early period of this research, which was conducted 10 months after forest harvesting and 4 months after forest fire, the existing natural regeneration was very rare. However, after one month of the research, natural regeneration was spreading fast and after only two months the forest floor was almost completely covered. After four months the vegetation cover was 29.9% with a density of 44 plants 100 m^{-2} and average height of 35.7 cm. The coverage projection is shown in Figure 1 and the debris coverage is in Figure 2.

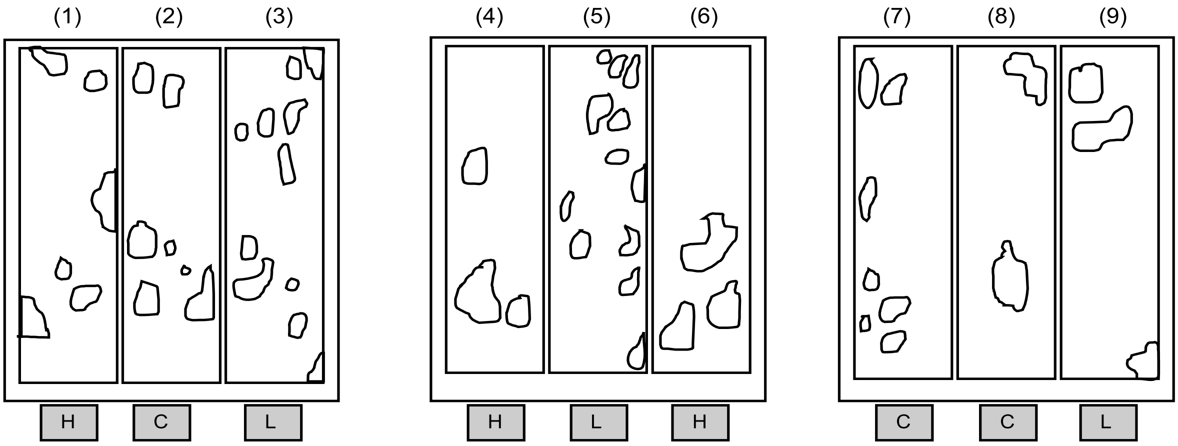
Methods

There were 9 x 1 ha plots established with 3 replications of 3 logging intensities (1) heavy intensity - commercial trees of dbh ≥30 cm were cut, (2) light intensity - commercial trees dbh ≥50 cm cut) and (3) control (no cutting). Erosion research plots 5 m x 20 m in area were placed in the three treatments. All ERP sites were on sites that suffered severe fires during February - March 1999. The nine plots were enclosed by timber inserted into the soil to about 5cm depth and cemented along the outer side of plots. At the end of the lowest part of the plot was an outlet 15-20 cm wide and 30-40 cm long. Two surface runoff collectors (60 litre capacity) were joined up in the lower part of each plot; the first collector was set higher than the second collector so that if the first collector became full of surface runoff water the surplus would flow into the second collector. Two or three simple rainfall collectors with a diameter of 10 cm and 1m length were placed around the plot.

The main parameters measured in each plot were: eroded soil mass (g), rainfall depth (mm), rainfall intensity (mm hour^{-1}), surface runoff (litre), natural regeneration cover (%), and litter cover on forest floor (%). Eroded soil mass was measured by sampling of soluted particle soils in surface runoff solution in the collector for each rainfall occurrences during 4-5 months of field observation. Vegetation cover percentage, litter position and dominant pioneer plant species were recorded periodically in each plot. Physical soil characteristics were taken from other research simultaneously conducted at the same study site.

Surface runoff (m^3 ha^{-1} year^{-1}) and eroded soil mass (t ha^{-1} year^{-1}) was then predicted by

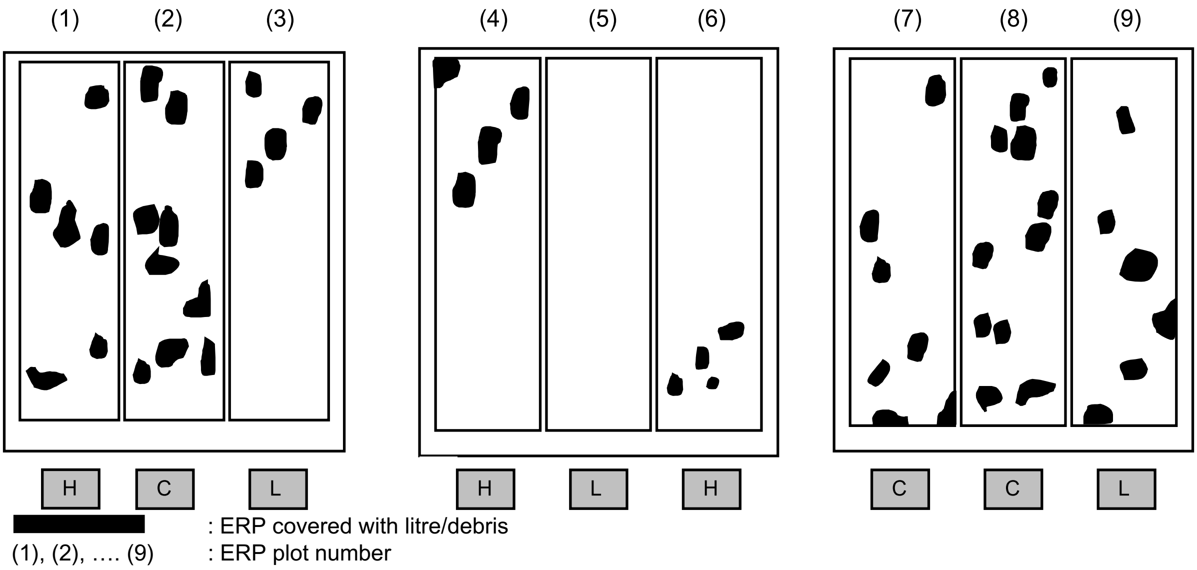
Figure 1. Projection of vegetation cover at each Erosion Research Plot



▭ : ERP covered with natural revegetation

(1), (2), …. (9) : ERP plot number

Figure 2. Projection of litter Cover at each Erosion Research Plot



extrapolating the original data collected for 4-5 months research period. The magnitude of predicted eroded soil mass was compared with the standard magnitude of permissible/acceptable/tolerable erosion rate to assess whether higher and/or lower viewed from considerable land productivity. Erosion of hazard class was found by comparing to the classification system of Class I (<15 t ha^{-1} year^{-1}), Class II (15-60 t ha^{-1} year^{-1}), Class III (60-180 t ha^{-1} year^{-1}), Class IV (180-480 t ha^{-1} year^{-1}), and Class V (>480 t ha^{-1} year^{-1}) respectively (Anonymous 1986, 1994). Erosion Hazard Level was assessed by combining of hazard erosion index and solum depth of soils as shown in Table 2.

RESULTS AND DISCUSSION

Soil erosion

In general, processes and soil erosion occurrences could be classified in sequential steps as soil aggregate detachment, soil particle dispersion, soils particle entrainment, and soil particle sedimentation. Field observation confirmed that these steps occurred. Rainfall mostly produced surface runoff in all research plots. These observations showed that forest logging followed by uncontrolled fires initiated surface runoff and soil erosion. However, the magnitude of soil erosion rate was still lower than the tolerable soil erosion rate.

Table 2. Classification of erosion hazard level

Erosion solum depth (cm)	Erosion hazard class				
	(I)	(II)	(III)	(IV)	(V)
	Erosion rates (t ha^{-1} year^{-1})				
	(<15)	(15~60)	(60~180)	(180~480)	(>480)
Depth (>90cm)	VL (0)	L (I)	M (II)	H (III)	VH (IV)
Moderate (60-90cm)	L (I)	M (II)	H (III)	VH (IV)	VH (IV)
Shallow (30-60cm)	M (II)	H (III)	VH (VI)	VH (IV)	VH (IV)
Very Shallow (<30 cm)	H (III)	VH (IV)	VH (IV)	VH (IV)	VH (IV)

VL: very light, L: light, m: moderate, H: heavy, VH: very heavy

As this research was not conducted immediately after forest fires, it is probable that the magnitude of eroded soil mass was lower than tolerable soil erosion rate. Most soil particles transported by surface runoff consisted of clay, silt and small amounts of sand. So it is assumed that organic materials or ash were mostly eroded before this research was conducted. It should be noted that surface runoff has a dominant role transporting dispersed soil particles. It was also very clear that a small amount of surface runoff sometimes transported soil particles only within the research plots and this before completely infiltrating the soil, and the next surface runoff would continue transportation of these eroded soil particles.

Dominant factors affecting soil erosion

Soil erosion processes and occurrences were simultaneously influenced by factors that work in a complex interaction with each other. Despite such complex interaction, it might be agreed that this interaction involves rainfall, soil erodibility, topography, vegetation cover and human activities. Among these factors, human activities are the most dominant factor influencing the increase of surface runoff and soil erosion and in this study logging activities caused the reduction of vegetation cover, allowing rain to impact directly on the forest floor. This phenomenon of rainfall causing soil aggregate detachment followed by soil particle dispersion was observed in the field. Soil compaction caused by logging activities directly reduced infiltration rate and capacity, and directly contributed to the increase of surface runoff when rainfall intensities were higher than infiltration capacities. Finally, the surface runoff following topography was potentially transporting dispersed soil particles to the various lower sites.

Total rainfall during 4 month period was 699 mm, other rainfall statistics are shown in Table 3. Surface runoff mostly occurred after the 40 rainfall events (Table 4).

Table 3. Rainfall amount and intensity during the research period (25 Oct. 1998-26 Feb. 1999)

Magnitude	Rainfall (mm)	Rainfall intensity (mm hour^{-1})
Total	699	
Mean	18	21
Minimum	1	2
Maximum	71	193

Note: data from 18 recorders at the edge of the research plots from 40 rainfall events.

Soil Erosion Characteristics

As a result of the rainfall in the observation period (Table 3) the volume of surface runoff was 993 litre ha^{-1} year^{-1} (heavy intensity), 1311 litre ha^{-1} year^{-1} (light intensity) and 1413 litre ha^{-1} year^{-1} (control) respectively (Table 4) These figures were compiled from direct measurement in the field and used to predict the eroded soil mass which was: 0.07 t ha^{-1} year^{-1} (heavy intensity), 0.05 t ha^{-1} year^{-1} (light intensity) and 0.06 t ha^{-1} year^{-1} (control) (Table 5).

To clarify the characteristics of the soil erosion process, possible relationships among factors influencing this process were analysed using a simple linear regression technique. The relationships were among rainfall amount, surface runoff (overland flow), and eroded soil mass (Table 6).

Table 4. Measurement of surface runoff/overland flow for each rainfall event

Magnitude	Surface runoff/overland flow					
	ERP(H)		ERP(L)		ERP(C)	
	(litre)	(litre ha^{-1}yr^{-1})	(litre)	(litre ha^{-1}yr^{-1})	(litre)	(litre ha^{-1}yr^{-1})
Total	2559	993	4711	1311	5122	1413
Mean	125	25	227	33	254	35
Minimum	0.5	0.1	0.5	0.2	0.5	0.2
Maximum	354	125	821	187	839	246

(H). Heavy logging or cutting intensity, (L). Light intensity, (C). Control.

Table 5. Eroded soil mass for each rainfall event

Magnitude	Eroded soil mass					
	ERP(H)		ERP(L)		ERP(C)	
	(g)	(t ha^{-1} year^{-1})	(g)	(t ha^{-1} year^{-1})	(g)	(t ha^{-1} year^{-1})
Total	243.5	0.073	151.8	0.046	201.4	0.060
Mean	6.1	0.001	3.8	0.001	5.0	0.002
Minimum	0	0	0.1	0	0.3	0
Maximum	31.5	0.009	21.7	0.007	19.4	0.006

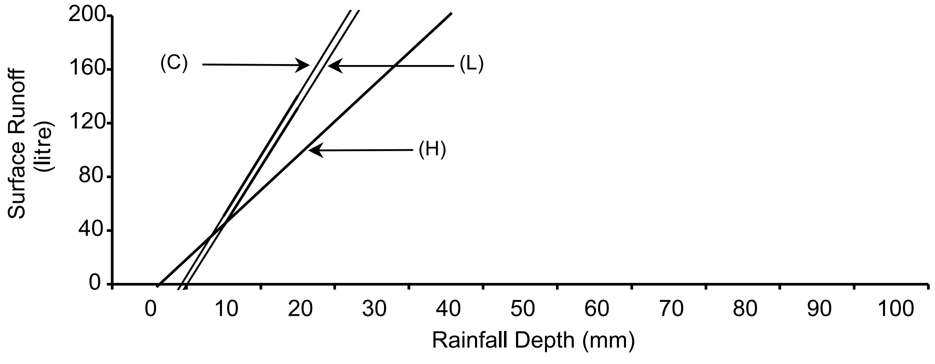
(H). Heavy logging or cutting intensity, (L). Light intensity, (C). Control.

Table 6. Correlations between rainfall amount, surface runoff (overland flow), and eroded soil mass at different logging intensities

Parameter	Erosion research plot	Regression equation	Correlation coefficient
Rainfall and surface runoff	(H)	$Y = 5.1296X - 6.9673$	0.78
	(L)	$Y = 8.7972X - 44.6030$	0.85
	(C)	$Y = 8.9477X - 38.7440$	0.72
Rainfall and eroded soil cover	(H)	$Y = 0.1992X + 2.5978$	0.26
	(L)	$Y = 0.0518X + 2.8893$	0.04
	(C)	$Y = 0.1086X + 3.1405$	0.14
Surface runoff and eroded soil cover	(H)	$Y = 0.0415X + 2.6477$	0.38
	(L)	$Y = 0.0062X + 3.1122$	0.05
	(C)	$Y = 0.0113X + 3.7136$	0.16

(H). Heavy logging or cutting intensity, (L). Light intensity, (C). Control.

Figure 4. Relationship between rainfall amount and surface runoff for each logging intensity in the erosion research plots



(H). Heavy logging or cutting intensity, (L). Light intensity, (C). Control.

High correlation coefficients (0.72-0.85) for rainfall and surface runoff indicate that the runoff increases with the amount of rainfall within a certain range (Table 6, Fig. 4) but there was little relationship between amount of rainfall and eroded soil cover, and surface runoff and eroded soil cover. This is generally found for the bare forest (bareland) under high rainfall with high intensity (Sudarmadji 1995).

Among the research plots, the control showed the highest surface runoff (5123 litres) compared with high intensity logging (2559 litres) and light intensity logging (4711 litres) treatments. It should be noted that the location of high intensity plots was a little steeper than others, and many tree parts remain inside the plots. Another reason was the wet soil condition caused by the previous rainfall occurrence. Fauzi (1996) and Fuliana (1996) reported that the interval between rainfall occurrences and vegetation remaining after logging strongly influence the magnitude of surface runoff. If there is a long interval between rainfall events, the soil condition will be drier than if rain occurs at shorter intervals and will favour greater infiltration rates and therefore less surface runoff. Conversely, if the interval was shorter while soil water was high, the magnitude of surface runoff would be greater.

In general, rainfall occurrences produce surface runoff transporting soil particles. However, raindrop impact does not always cause soil disaggregation, soil dispersion and soil erosion in the way as it is affected by previous conditions. High rainfall does not always produce more eroded soil mass than rainfall (Sudarmadji 1995). It is clear that the soil erosion is affected by several factors and occurs step by step depending on these factors.

The light intensity logging resulted in the least eroded soil mass compared to the others, possibly due to the remaining trees in the stand retarding surface runoff and soil erosion. The slope of this plot was less steep than in others. Surface runoff was an important factor influencing soil erosion. Referring to the relationship between rainfall amount and surface runoff and also eroded soil mass, the increase of rainfall tended to increase surface runoff (Gunawan 1996). However, increasing rates of eroded soil with the increase of surface runoff were different in the three treatments plots suggests that there were other strong factors such as lower soil erodibility, or not enough existing dispersed soil particles ready to be transported by surface runoff.

Magnitude of Soil Erosion and its Hazard Indices

Both soil erosion hazard class and index of soil erosion hazard level can be used as indicators to assess the impact of logging and forest fires on soil erosion rate and determine if it is higher or lower than tolerable/acceptable/permissible erosion rates. Each landscape has its own characteristics of soil erodibility and soil susceptibility and logging followed by forest fires would increase soil erodibility and soil susceptibility. Susceptibility refers to factors other than soil characteristics, such as slope, rainfall, etc., which influence the soil erosion events.

It is possible for assessment based on these indicators to be used as an important consideration for developing guidelines for implementation of logging activities. Further, such assessment could assist decision making on the need for soil erosion control measures and/or degraded land rehabilitation. Various soil erosion rates are frequently found in logged-over forest and an interpretation technique to assess them is urgently needed. The soil erosion hazard class and index of soil erosion hazard level offer a good solution. Classifying the measured magnitude of eroded soil mass into Classes I-V provides the basis for such assessment. Combining the soil erosion hazard class with its solum depth provides the index of hazard level soil erosion ranging from very light (VL) to very heavy (VH). The soil depth in study sites was very deep (>100cm), thus the assessment showed all treatments are very low soil erosion hazard index (Table 7) so measures to control erosion or improve the site are not urgent.

Table 7. Prediction of Eroded Soil Mass, Soil Erosion Hazard Class and Index of Soil Erosion Hazard Level

Logging intensities	Soil Erosion Magnitude ($t\ ha^{-1}\ year^{-1}$)	Soil Erosion Hazard Class	Index of Soil Erosion Hazard
High (dbh ≥30cm cutting)	0.07	I	VL
Light (dbh ≥50cm cutting)	0.05	I	VL
No logging (Control)	0.06	I	VL

Note: I = <15 $t\ ha^{-1}\ year^{-1}$, VL: very low

Minimising Impact of Logging and Forest Fire on Soil Erosion

Forest harvesting to extract commercial trees causes unavoidable impact, especially an increase of surface runoff and probably also of soil erosion rates. Hence, the most important question is whether forest harvesting followed by fires has brought about a serious threat to the sustainable forest land productivity. The answer will be very important in decisions as to whether erosion control measures and degraded land rehabilitation are needed. Such decisions have to be carefully examined due to the very high costs, time and manpower involved.

CONCLUSIONS

The most important conclusions of this research are:

- Both heavy and light intensity logging followed by uncontrolled forest fires increased surface runoff and in some cases also soil erosion rate.
- Increase of the amount of rainfall tended to increase surface runoff and therefore possibly increase eroded soil mass.
- Eroded soil mass did not always increase following increased surface runoff.
- Vegetation cover can retard surface runoff and soil erosion.
- The rate of soil erosion in logged-over forest lands (heavy, light and no logging intensities) followed by severe forest fire was still acceptable/tolerable/permissible, according to the research conducted 1.5 years after the logging and 6-10 months after the fire. Therefore, the land degradation risk is tolerable from a land productivity viewpoint and there is no immediate need for erosion control measures and land rehabilitation work.

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Inventory of Diseases on Dipterocarps in Natural Forest with Different Cutting Intensities and on Mixed Species in a Taungya System Plantation

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Abstract

The research was conducted at Bukit Soeharto, East Kalimantan, Indonesia. In the natural forest there were as many sound as diseased trees. There were no clear differences in disease incidence among forests with different intensities of cutting and among different diameter classes. Observations were made on 49 trees of 15 species in sample plots. Among them only *Dipterocarpus convertus*, *D. cornutus*, *Shorea leprosula*, *S. ovalis* and *S. seminis* remained sound. Stem canker was judged to be the most dangerous disease. Invasion of disease in uncut forest (control) was low level compared with cutting treatments, but difference of disease invasion between the forests with different cutting intensities was not clear because of low numbers of sample trees. Sound trees should be preferred to diseased trees for seed trees. In the taungya plantation there were generally more sound plants of all species compared to diseased and dead ones, except for *Manihot esculenta* and *Glycine max* which were more diseased than sound. Leaf spots were found in all species of plants. Among the forestry plants, the highest incidence of leaf spot disease occurred in *Hevea brasiliensis* and among the agricultural plants, the highest incidence was in *G. max*. Generally, invasion of diseases in *M. esculenta* and *G. max* caused moderate damage, while other species had a low level of damage. Mixed planting in the taungya system presents no problem from disease viewpoint because of the specificity of the diseases.

INTRODUCTION

Dipterocarps from natural forests have for a long time provided wood for plywood, fibreboard, particleboard, moulding and other building materials. The species are being established in large-scale plantation of timber estates project in Indonesia. There are many reports of diseases, mainly on fast-growing exotic species, while there are still few reports of diseases of dipterocarps in plantations and natural forests. Bacterial, viral and some fungal diseases on seedlings and saplings of *Shorea* spp., have occurred in natural and plantation forests in Indonesia, Malaysia, Thailand and the Philippines as reported by Smits *et al.* (1991) and a general review of diseases on dipterocarps was made by Elouard (1998). In the natural forest in the Philippines *Botryodiplodia theobromae* caused the death of regeneration of *Dipterocarpus grandiflorus* under big mother trees, and sapling mortality reached 40% due to *Polyporus* sp., *Humicola* sp. and *Macrophoma* sp. (Quiniones 1980). *Dipterocarpus oblongifolius* seedlings were killed in Peninsular Malaysia by *Cylindrocladium scoparium* (Lee and Ahmad 1982). Soeyamto and Mardji (1995)

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reported the attack of unknown fungi causing root-rot and stem canker in one-year-old *Shorea leprosula* in the plantation of PT. Kiani Hutani Lestari at Batu Ampar (East Kalimantan).

Natural dipterocarp and secondary forests in the Bukit Soeharto Educational Forest of Mulawarman University were burnt in February-March 1998. Before the fires, diseases of seedlings and saplings of dipterocarp species in the natural forest with different intensities of cutting were assessed by Arsensi (1998). Based on the number of infected regeneration, leaf spot had the highest incidence, followed by leaf blight, dieback, and stem canker. Crown gall had the lowest incidence. All the diseases had a low level of severity. The condition of the forest changes after burning and that can affect disease severity. It may increase because many trees are dead or damaged and provide pathogens with alternative substrates, or because temperatures rise, due to higher radiation from sunlight, many pathogens may be suppressed. In this study, the research was limited to dipterocarp species with a breast height diameter (bhd) of 10 cm and above.

A plantation forest was established in a burnt area using a taungya system with the following combinations: rubber (*Hevea brasiliensis*) + corn (*Zea mays*), rubber + paddy rice (*Oryza sativa*), rubber + cassava (*Manihot esculenta*), red meranti (*Shorea smithiana*) + soybean (*Glycine max*) and red meranti + paddy rice. There had been were no previous research of diseases of such systems in East Kalimantan. The environmental condition of the plantation area is different from natural forest, e.g. air temperature and humidity in the plantation area are higher, so it is possible diseases found in the plantation and natural forest are different.

The research was conducted at Bukit Soeharto, East Kalimantan, Indonesia, in natural dipterocarp forest and in a taungya plantation. Field observations were conducted in December 1998 and January 1999 followed by laboratory observations in the Laboratory of Forest Protection, Faculty of Forestry, Mulawarman University, Samarinda.

The objectives of the research were to determine:

- symptoms and signs of diseases in dipterocarps in natural forest with different intensities of cutting,
- symptoms and signs of diseases in trees and agricultural plants in the taungya system,
- the most virulent pathogen predicted to be a future threat,
- which species were resistant,
- sum of diseased and sound trees and seedlings,
- which size of trees were the most severely infected by diseases,
- if the combination of forestry and agricultural plants was suitable from disease point of view?

STUDY SITE DESCRIPTION AND METHODS

Observation in Natural Forest

The Bukit Soeharto Education Forest (BSEF) is located at 1^{o} S latitude and 117^{o} E longitude and 43 km from Samarinda, East Kalimantan. The climate is hot and wet throughout the year and typical for a tropical rain forest region (Toma *et al.* 2000). The average annual rainfall is 2002 mm and average annual total evaporation 1273 mm. The yearly mean air temperatures is 29.9ϒC for daily maximum and 21.4ϒC for daily minimum. The mean annual relative air humidity is 93% for daily maximum and 59% for daily minimum. The original vegetation is lowland mixed dipterocarp forest that has been logged sporadically by local inhabitants and selectively by timber companies BSEF became a protected forest in 1979.

In East Kalimantan, an unusually prolonged and severe drought lasted from June 1982 to April 1983. It was linked to a strong El Nino Southern Oscillation (ENSO) event (e.g. Goldammer *et al.* 1996). Another strong ENSO event occurred in 1997 and extended into 1998 and there were two rainless periods in East Kalimantan during this event (Toma *et al.* 2000). During 1982-83 and

1997-98 huge areas of rain forest in East Kalimantan, including BSEF, were affected by droughts and drought-related fires (Mori 2000).

In May 1997, a 9 ha permanent plot was established by Dr.Y. Ruslim to investigate the effects of a second felling in a logged-over dipterocarp forest and subsequent recovery from the felling. The plot included nine 1-ha subplots (100 m x 100 m) giving three replications of without cutting (control forest), and low and heavy intensities of cutting. The low intensity treatment involved cutting trees >50 cm breast height diameter and the heavy intensity cutting trees >30 cm bdh. Some trees were left as seed trees even though they were large enough to cut. The 9 ha plot was burnt February-April 1998.

The disease research was conducted in the three cutting treatments in 25 subplots (20 m x 20 m) respectively, with observations on dipterocarps with >10 cm bhd. There were 113 subsample plots covering 4.5 ha. The following data was recorded:

- disease symptoms in each tree species e.g., chlorosis, stem gall, stem canker and dieback. Infected parts were taken for laboratory identification.
- causal agent of diseases, e.g., fruit bodies of fungi.
- tree bdh measured with a Phi-band at 1.30 m from soil surface.
- number of infected and sound trees.
- air temperature and humidity of each cutting treatment measured with a thermohygrograph during one month.

Assessment of the infection on individual trees in natural forest was based on the symptoms observed. The scoring system of the symptom (Table 1) was modified from Eusebio *et al.* (1979) and Sharma *et al.* (1984).

Table 1. Scoring system used to assess disease severity on the individual plant in natural forest and in plantation

Disease symptom	Score
Nil (no infection symptom or present but the number of infected leaves and the width of lesion are very few compared to the width of all leaves, plant remains sound)	0
Low (number of infected leaves and number of lesions on each leaf are few or little defoliation or chlorosis has occurred or plant looks sound but other symptoms such as stem canker are present)	1
Medium (number of infected leaves and number of lesions on each leaf are many or much defoliation or chlorosis has occurred or other symptoms such as stem canker or dieback are present)	2
Severe (number of infected leaves and number of lesions on each leaf are abundant or abundant defoliation or chlorosis has occurred or other symptoms such as stem canker or dieback are present)	3
Highly severe (number of infected leaves and number of lesions on each leaf are very extensive or extensive defoliation or chlorosis has occurred or other symptoms such as stem canker or dieback are present).	4
Dead (all leaves are wilted or defoliated or no life indication)	5

Observation in Plantation Forest

The area was a burnt by wild fire in 1998 and then cleared of remaining debris. Some big living trees were not cut. Two sample plots (100 m x 100 m each) were established and consisted of 25 subsample plots (20 m x 20 m), respectively. The subsample (observation) plots were designed for systematic random sampling. The taungya plantings made in October 1998 were: rubber (*Hevea brasiliensis*) + corn (*Zea mays*), rubber + paddy rice (*Oryza sativa*), rubber + cassava (*Manihot esculenta*), red meranti (*Shorea smithiana*) + soybean (*Glycine max*) and red meranti + paddy rice. When disease observations were made the trees were still in seedling stage and 50 cm high. Planting distances were: rubber 5 m x 5 m, red meranti 7 m x 7 m, cassava 1 m x 1 m, corn and soybean 0.5 m x 0.5 m and paddy rice 0.25 m x 0.25 m.

Invasion of pathogens on each species was observed on leaves, twigs, stems and roots.

Assessment was made as shown in Table 2. The infected part of plant was brought to the laboratory for identification of the causal agent. The following data were recorded:

- symptoms of diseases, e.g., leaf spot, chlorosis, stem gall, stem canker and dieback.
- the causal agents of diseases.
- number of infected and sound trees.
- air temperature and humidity measured with a thermohygrograph during one month.

Table 2. Level of damage in each species of tree or plant based on disease severity

Severity (%)	Level of damage
0 ~ 1	sound
> 1 ~ 25	low
> 25 ~ 50	medium
> 50 ~ 75	severe
> 75 ~ 100	highly severe

Observation in Laboratory

Identification of causal organisms was under a microscope in the Laboratory of Forest Protection, Faculty of Forestry, Mulawarman University, Samarinda. All pathogens were isolated in Petri dishes containing potato dextrose agar for further observations and identification.

Data Analysis

Incidence (frequency) of disease attack (I) was calculated according to the formula of James (1974) as follows:
I = (number of infected and dead trees or plants / number of observed trees or plants) x 100%.
Severity (intensity) of disease attack (S) was calculated according to the formula of de Guzman (1985), Singh and Mishra (1992) modified as follows:

$$S = \{(X1Y1 + X2Y2 + X3Y3 + X4Y4 + X5Y5) : (XY5)\} \times 100\%.$$

S = severity of attack
X = number of observed trees or plants of each species
X1~X5 = number of trees or plants of each species with score 1 to 5
X5 = number of trees or plants of each species with score 5
Y1~ Y5 = score 1 to 5

After obtaining the severity of attack score, the level of damage in each species was determined.

RESULTS AND DISCUSSION

Disease in Natural Forest

Most of the dipterocarp species (seed trees) were killed by the forest fire, so there were only 49 living trees of dbh 10 cm and above in 113 sample plots (Table 3). There were 36 living trees in the uncut control, 10 trees in the low intensity cutting and 3 trees in the heavy intensity cutting. For this reason, they cannot be compared with each other to determine the effect of different intensities of cutting on the occurrence of disease. Overall there were 26 sound trees (53%) and 23 diseased trees (47%). Dead trees were not recorded because it was difficult to identify whether death was caused by fire, disease, disease before fire, or both fire and disease. There were 15 species of living trees in the subsample plots. *Dipterocarpus convertus*, *D. cornotus*, *Shorea leprosula*, *S. ovalis* and *S. seminis* remained free from disease. It was not possible to decide which species was the most resistant because of the small number of trees of each species. The greatest number of diseased trees occurred in the diameter class >50-70 cm (7 trees) and the least was in class >70-90 cm (2 trees) (Table 4). There were also very few living trees in the subsample plots, the results were shown without treatments of cutting intensities.

The diseases found in the natural forest were stem canker, dieback, gall and a combination of these (Table 5). Stem canker was the most frequently found with 13 infected trees (36%) in control forest, 3 trees (30%) in the low intensity cutting and none in heavy intensity cutting. These diseases seemed to be present in the area long before the 1998 forest fire, because their symptoms

Table 3. Number of sound and diseased trees in natural forest with different intensities of cutting (numerals in parentheses are a percentage)

Intensity of cutting	Species	Total	Sound	Diseased
Control (without cutting)	*Dipterocarpus convertus*	1	1	0
	D. cornotus	2	2	0
	D. humeratus	2	1	1
	D. tempehes	3	1	2
	Shorea accuminatissima	2	1	1
	S. bracteolata	1	0	1
	S. gibbosa	1	0	1
	S. johorensis	1	0	1
	S. laevis	9	4	5
	S. leprosula	2	2	0
	S. ovalis	3	3	0
	S. parvifolia	1	0	1
	S. seminis	2	2	0
	S. smithiana	6	2	4
	Total	36	19 (52.8)	17 (47.2)
Low intensity cutting	*Cotylelobium lanceolatum*	1	0	1
	S. gibbosa	1	0	1
	S. johorensis	4	3	1
	S. ovalis	1	1	0
	S. parvifolia	1	0	1
	S. smithiana	2	1	1
	Total	10	5 (50)	5 (50)
Heavy intensity cutting	*D. cornotus*	1	1	0
	S. smithiana	2	1	1
	Total	3	2 (66.7)	1 (33.3)
	Total of all trees	49	26 (53.1)	23 (46.9)

Table 4. Number of sound and diseased trees in different breast height diameter classes in natural forest

Diameter class (cm)	Total of trees	Sound trees	Diseased trees
10 ~ 30	16	10	6
>30 ~ 50	12	7	5
>50 ~ 70	10	3	7
>70 ~ 90	7	5	2
>90	4	1	3
Total	49	26	23

Table 5. Number of diseased trees with each type of disease in natural forest with different intensities of cutting (numerals in parentheses are a percentage)

Intensity of cutting	Tree species	Total	Stem canker (Sc)	Dieback (Db)	Gall(G)	Sc+Db	Sc+G
Control	*D. convertus*	1	0	0	0	0	0
	D. cornotus	2	0	0	0	0	0
	D. humeratus	2	1	0	0	0	0
	D. tempehes	3	2	0	0	0	0
	S. accuminatissima	2	0	0	1	0	0
	S. bracteolata	1	0	0	0	1	0
	S. gibbosa	1	1	0	0	0	0
	S. johorensis	1	1	0	0	0	0
	S. laevis	9	3	0	1	0	1
	S. leprosula	2	0	0	0	0	0
	S. ovalis	3	0	0	0	0	0
	S. parvifolia	1	1	0	0	0	0
	S. seminis	2	0	0	0	0	0
	S. smithiana	6	4	0	0	0	0
	Total	36	13 (36.1)	0	2 (5.5)	1 (2.8)	1 (2.8)
Low	*C. lanceolatum*	1	1	0	0	0	0
	S. gibbosa	1	0	1	0	0	0
	S. johorensis	4	1	0	0	0	0
	S. ovalis	1	0	0	0	0	0
	S. parvifolia	1	1	0	0	0	0
	S. smithiana	2	0	1	0	0	0
	Total	10	3 (30.0)	2 (20.0)	0	0	0
Heavy	*D. cornotus*	1	0	0	0	0	0
	S. smithiana	2	0	0	1	0	0
	Total	3	0	0	1 (33.3)	0	0
	Total of all trees	49	16 (32.7)	2 (4.1)	3 (6.1)	1 (2.0)	1 (2.0)

were already well developed. The cankers were mostly found at the bottom of the trunk indicating that the causal fungi infected through the basal part of the stems and/or roots. It is not known when and how the fungi penetrated their hosts. It is well known that many species of fungi are able to enter their hosts through lenticels, wounds or intact surfaces. The fungi causing stem canker in the research area probably entered their hosts through wounds, and cankers seemed to be the most dangerous disease. It is difficult to control this disease because there are many causal agents of wounds, such as insects, wild animals, mechanical injuries and fire. Dieback disease was found in only 2 trees (20%) in the forest with low intensity cutting, gall was in 2 trees (20%) in the control forest and in 1 tree (33%) in the heavy intensity cutting.

The number of diseased trees in each diameter class in natural forest is given in Table 6. Diseases occurred in all diameter classes but the greatest number of diseased trees was in >50-70 cm (6 trees cankered and 1 tree gall) and the least was in >70-90 cm (1 tree dieback and 1 gall). The incidence and severity of diseases in the different intensities of cutting are shown in Table 7. Average incidence and severity of diseases in the natural forest were 47% and 22% respectively. Although it is very difficult to show the effect of cutting intensity because of the small number of sample trees, there is tendency for invasion by diseases in the low intensity of cutting because of moderate harvesting damage, while in control and in heavy intensity of cutting there was a lower level of damage.

Temperature and Relative Humidity in Natural Forest

Average temperature in the control forest was 25.5°C, with a minimum 20.4°C and maximum 37.4°C, at low intensity of cutting site (LC) these temperatures were 25.4°C, 20.6°C and 34.8°C respectively, and at heavy intensity of cutting site (HC) they were 27.3°C, 22.4°C and 37.6°C respectively. Average humidity in the control forest was 95%, the minimum was 77% and the maximum was 100%, in LC humidity was 82%, 43% and 100%, and in HC it was 81%, 31% and 100% respectively. The average humidity in LC and HC was almost same, but was far higher in the control forest. Lack of trees made it impossible to relate temperature and humidity to disease development.

Disease in Plantation Forest

Most species were mainly sound with the exception of *Manihot esculenta* and *Glycine max* which had more diseased than sound plants (Table 8). Disease incidence on the agricultural plants was mainly on plants stunted by nutrient deficiency which could be solved by fertilisation. *Hevea brasiliensis* had more sound trees than *Shorea smithiana* and in the agricultural plants, *Oryza sativa* had the highest percentage of sound plants. The high level of deaths in *M. esculenta* was a stem rot caused by an unidentified fungus which probably invaded the cuttings. The other plants seeds were planted.

Table 6. Number of diseased trees in different breast height diameter classes in natural forest

Diameter class (cm)	Stem canker (Sc)	Dieback(Db)	Gall(G)	Sc+Db	Sc+G
10 ~ 30	4	0	1	1	0
>30 ~ 50	3	1	0	0	1
>50 ~ 70	6	0	1	0	0
>70 ~ 90	0	1	1	0	0
>90	3	0	0	0	0
Total	16	2	3	1	1

Table 7. Incidence (I) and severity (S) of diseases in natural forest with different intensities of cutting

Intensity of cutting	Sound trees	Diseased trees						I	S	Level of damage
		Total	Low	Medium	Severe	Highly severe	Dead	(%)		
Control	19	17	6	4	6	1	0	47.2	20.2	Low
Low	5	5	0	1	2	2	0	50.0	32.0	Moderate
Heavy	2	1	0	1	0	0	0	33.3	13.3	Low
Total	26	23	6	6	8	3	0	46.9	22.0	

Table 8. Number of sound and diseased plants in taungya plantation forest (numerals in parentheses are a percentage)

Species	Total	Sound	Diseased	Dead
Shorea smithiana	45 plants	25 (56)	20 (44)	0
Hevea brasiliensis	75 plants	52 (69)	22 (29)	1 (1)
Manihot esculenta	671 plants	259 (39)	292 (44)	120 (18)
Zea mays	1216 clumps	780 (64)	436 (36)	0
Glycine max	1967 clumps	54 (3)	1913 (97)	0
Oryza sativa	5697 clumps	4590 (81)	1107 (19)	0

Six diseases, leaf spot, leaf blight, leaf wrinkle, chlorosis, stunt and dieback, were found in the plantation. Leaf spot diseases were found in all species (Tables 9 and 10) with the highest incidence in *H. brasiliensis* in the trees and *G. max* in the agricultural plants. The next most frequent disease was stunt disease, especially in agricultural plants. The highest incidence was in *M. esculenta* but *H. brasiliensis* was also affected. The causal agents of leaf spot, leaf blight and dieback were unidentified fungi, leaf wrinkle was due to a virus, while chlorosis and stunt were a nutrient deficiency problem. The level of damage of diseased plants was generally low (Table 11). The incidence and severity of diseases in *O. sativa* were the lowest (19% and 6% respectively), while the highest rate of disease incidence occurred in *G. max* (97%) with the severity of 30% followed by the second highest incidence and severity of diseases in *M. esculenta* (61% and 33%, respectively). The high rate of disease incidence on *G. max* was mostly caused by leaf spot, while the high rate of severity on *M. esculenta* was mostly caused by stunted plants. Regular fungicide treatment is recommended on *G. max* to control leaf spot disease and fertiliser application and weeding for *M. esculenta*. Treatment with a systemic fungicide of *M. esculenta* stems after cutting or before planting is prerequisite to avoid infection by stem rot fungi. It can be concluded that mixed planting in the taungya system presents no problem from disease view point because of the specificity of the diseases.

Temperature and Relative Humidity in Taungya Plantation

Average temperature was 24.5°C and humidity was 82%. Leaf spot disease occurred in all species which indicates the causal fungi tolerate these climatic conditions. In the open area minimum temperature was 19°C and the maximum 35°C, while minimum humidity was 28% and maximum humidity 85%.

Table 9. Number of diseased plants based on each type of disease in taungya plantation forest

Plant species	Ls[1]	Lb	Lw	C	S	Db	Ls+Lb	Lb+Db	Lb+S	Ls+C	Ls+S
Shorea smithiana	3	10	0	0	3	0	2	1	1	0	0
Hevea brasiliensis	17	0	0	0	0	4	0	0	0	1	0
Manihot esculenta	75	0	0	25	181	0	0	0	0	0	11
Zea mays	93	0	12	49	250	0	0	0	0	0	32
Glycine max	1291	0	0	0	200	0	0	0	0	0	439
Oryza sativa	99	0	0	0	967	0	0	0	0	0	41

[1] Ls = leaf spot. Lb = leaf blight. Lw = leaf wrinkle. C = chlorosis. S = stunt. Db = dieback.

Table 10. Incidence of disease (%) based on each type of disease in taungya plantation forest

Plant species	Ls[1]	Lb	Lw	C	S	Db	Ls+Lb	Lb+Db	Lb+S	Ls+C	Ls+S
Shorea smithiana	6.7	22.2	0	0	6.7	0	4.4	2.2	2.2	0	0
Hevea brasiliensis	22.7	0	0	0	0	5.3	0	0	0	1.3	0
Manihot esculenta	11.2	0	0	3.7	27.0	0	0	0	0	0	1.6
Zea mays	7.7	0	1.0	4.1	20.5	0	0	0	0	0	2.6
Glycine max	65.6	0	0	0	10.2	0	0	0	0	0	21.9
Oryza sativa	1.9	0	0	0	18.4	0	0	0	0	0	0.8

[1] Ls = leaf spot. Lb = leaf blight. Lw = leaf wrinkle. C = chlorosis. S = stunt. Db = dieback.

Table 11. Incidence (I) and severity (S) of diseases in taungya plantation forest

Plant species	Sound plants	Diseased plants					I (%)	S (%)	Level of damage
		Low	Medium	severe	Highly severe	Dead			
Shorea smithiana	25	8	3	6	3	0	44.4	18.2	low
Hevea brasiliensis	52	19	0	0	3	1	30.7	9.6	low
Manihot esculenta	259	136	104	45	7	120	61.7	33.0	moderate
Zea mays	780	154	107	84	91	0	35.9	16.2	low
Glycine max	54	1197	480	200	36	0	97.2	29.5	moderate
Oryza sativa	4590	761	169	170	7	0	19.4	5.8	low

Notes on the Diseases in Natural Forest

Stem Canker

This was found on *Cotylelobium lanceolatum*, *Dipterocarpus humeratus, D. tempehes*, *Shorea gibbosa*, *S. johorensis*, *S. laevis*, *S. parvifolia* and *S. smithiana*. The causal agents were unidentified fungi. Stem canker occurred in the stem near the ground and/or expansion of root canker to the stem. Wounds to root and stem bark and also dead branch stubs seemed to be the point of infection. The infected parts of the stem were slightly swollen (hypertrophy). Severe infection resulted in dieback. The symptoms of infected dipterocarps were similar to other tree species. Sharma *et al.* (1985, 1986) reported dieback on *Eucalyptus* spp. infected by *Corticium salmonicolor* (also causes stem canker/pink disease) was the effect of toxic substances which caused damage on wood cells and resulted in leaf wilting. While Gäumann (1951) and Butin (1989) noted that wilting diseases of other tree species were caused by damage of water transportation cells resulted from the infection by microorganisms.

Dieback

This was found in *S. bracteolata*, *S. gibbosa* and *S. smithiana*. The symptoms were similar to the stem canker. The difference was that dieback had no wound or canker, but the shoot died by showing necrotic symptoms starting from the apex and progressing downwards toward the main stem. The colour of the infected shoot changed from bright to dark, hence sound and infected stems were clearly different since the shoot defoliated and sometimes epicormic branches appeared. The branch died when the pathogen extended to the basal part of the shoot. The causal fungus of the dieback in dipterocarps is not known yet. Stagnating disease in *Eucalyptus* spp. in Brazil and India is caused by *Cylindrocladium quinqueseptatum* (Gibson 1975, Singh and Chaturvedi 1993). *Eucalyptus urophylla* in Sumatra is also infected by *Cylindrocladium quinqueseptatum* (Nuhamara 1991). *Cassia fructicosa* dieback in the Philippines is caused by *Diatrypella favacea* and *Valsa kitajimana* (Kobayashi and de Guzman 1988).

Gall/Tumour

This disease was found in *S. accuminatissima*, *S. laevis* and *S. smithiana*. Globose or subglobose swellings known as galls (burls, crown galls) were common on these trees. According to Boyce (1961), there are noninfectious galls caused by an injury and infectious galls caused by bacteria. The causal agent of stem gall in dipterocarp species is not known.

Notes on the Diseases in Taungya Plantation

Leaf Spot

This was the most frequent disease found in the area. Symptoms of the leaf spot differed among each species, and identifications revealed the causal agents were fungi of different species, some of which remained unidentified. The fungi were *Helminthosporium maydis* syn. *Bipolaris maydis* in *Zea mays* and *H. oryzae* syn. *Bipolaris oryzae* syn. *Cochliobolus miyabeanus* in *Oryza sativa* and unidentified fungi in *Shorea smithiana*, *Hevea brasiliensis* and *Manihot esculenta*.

Dieback

Dieback was found in *H. brasiliensis* with very low incidence, the symptoms were similar to the stem canker noted above, but the causal fungus was unidentified.

Stunt

Stunt disease occurred in all species except *H. brasiliensis*. It is usually the result of lack of light or water, or nutrient deficiency.

Chlorosis

This is a yellowing symptom of some or all leaves in a plant. This is generally caused by disease or nutrient deficiency. Almost all leaves in a plant with this symptom in the research sites were yellowish. The symptoms were found on some plants of *M. esculenta* and *Z. mays* and chlorotic leaves were often followed by insect attack.

Leaf Blight

This disease was found only in *S. smithiana*. Symptoms were necrosis of the leaves which began from the edge of leaves and then expanded to the middle. The form of necrosis was not regular. The causal agent was an unidentified fungus. According to Mardji (1996), this disease is found in *Dryobalanops beccarii*, *Dipterocarpus humeratus*, *S. bracteolata* and *S. pauciflora* at Bukit Soeharto. The causal agents of the leaf blight on *Dryobalanops beccarii* were *Colletotrichum* sp. and *Pestalotiopsis* sp. The leaves of *D. humeratus* were infected by *Colletotrichum* sp., but *S. bracteolata* and *S. pauciflora* were infected by unidentified fungi. *Pestalotiopsis* consists of over 200 species, most of them pathogens for important plants in nurseries and in plantations of agricultural and forestry plants (Stevens 1966). Kobayashi and de Guzman (1988) reported *Pestalotiopsis adusta* on *Anacardium occidentale* and *P. langloisii* on *Calliandra haematocephala*. *Pestalotiopsis* sp. caused dieback in seedlings of *Swietenia macrophylla* in East Kalimantan (Mardji 1995). However, species of *Pestalotiopsis* often attacks parts infected by other pathogens so the pathogenicity of this fungal group as a primary parasite seems doubtful.

Leaf Wrinkle

Leaf wrinkle results from excessive cell division or from an abnormal increase in size of cells (Boyce 1961). It disease affected only leaves of *Zea mays*. Most of the leaves in a plant were wavy and rather hard, but remained green and the plant health seemed unaffected. The causal agent was probably a virus. Only 1% of plants were affected so this disease was not considered dangerous in the research area.

CONCLUSIONS

The difference of disease invasion between forest with different cutting intensities was not clear because of low number of sample trees. Diseases found in the natural forest were stem canker, dieback, gall and a combination of these. Stem canker was the most frequently found and seemed to be the most dangerous disease. In the taungya plantation there were generally more sound plants of all species compared to diseased and dead ones, except for *Manihot esculenta* and *Glycine max* which were more diseased than sound. Leaf spots were found in all species of plants. Among the forestry plants, the highest incidence of leaf spot disease occurred in *Hevea brasiliensis* and among the agricultural plants, the highest incidence was in *G. max*. Generally, invasion of diseases in *M. esculenta* and *G. max* caused moderate damage, while other species had a low level of damage. Mixed planting in the taungya system presents no problem from disease viewpoint because of the specificity of the diseases.

RECOMMENDATIONS

- Uncut trees that served as seed trees in natural forest and which are diseased should be replaced by sound trees.
- Plants stunted due to nutrient deficiency in plantations should be fertilised immediately after the emergence of their juveniles and well before flowering. Regular treatment with fungicide is recommended to control leaf spot disease in taungya systems. Treatment with a systemic fungicide for *M. esculenta* stems after cutting or before planting is necessary to avoid infection by stem rot fungi.

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6

Effects of Forest Fire on Wood: A Biological (Anatomical Study)

A.S. Budi[1]

Abstract

The effects of forest fire on wood were studied on fifteen dead and living trees of various tropical species. The wood reacted in the following ways: (1) creating smaller but denser pores than normal in a concentric pattern, (2) changing dimension and numbers of axial parenchyma, (3) producing more axial intercellular canals, (4) forming decay spots in the wood, (5) creating the concentric area of fibres area or forming the vessels late, (6) creating new calluses and the bole losing its cylindrical form, (7) producing abnormal gums in the wood and (8) the bole becoming hollow. These abnormalities decrease physical or mechanical properties depending on how serious the defect is in the wood. Wood deterioration was more strongly influenced by the conditions caused by the forest fire and subsequent attacks by fungi, bacteria and insects than by fire itself. There were various effects depending on the durability and other properties of the wood. The wood was classified into four groups: “merkubung/sengon”, “akasia/medang”, “ulin” and “leda”, according to condition in the field.

INTRODUCTION

In nature, wood is one of the reliable materials for recording data of past events. If a tree survives frequent forest fires, air pollution and other drastic ecological changes, the physical wounds will be recorded in the wood. Reactions among trees vary according to the tree species and/or wounding process. Several times forest fires in East Kalimantan have almost destroyed our forest plantations, leaving just a few living trees in various conditions. Up to now, industrial and governmental managers have hesitated about decisions on how to manage the forest after fire, especially whether or not to cut dead trees. However, the wood will deteriorate in time if the dead-standing trees are left.

The aim of the research was to determine what wood deterioration occurs in the standing tree in a burnt area, and what changes take place in the fire-damaged structures one year after the fire. Further, to make a timber classification to assist collection of timbers from the field after forest fires.

MATERIAL AND METHODS

The wood samples were taken from Tahura Bukit Suharto Education Forest (BSEF) of Mulawarman University located at 1° S latitude and 117° E longitude and 43 km from Samarinda, East Kalimantan. The climate is hot and wet throughout the year and typical for a tropical rain forest region. The average annual rainfall is 2002 mm and

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average annual total evaporation 1273 mm. The yearly mean air temperatures is 29.9^{0}C for daily maximum and 21.4^{0}C for daily minimum. The mean annual relative air humidity is 93% for daily maximum and 59% for daily minimum. The original vegetation is lowland mixed dipterocarp forest that has been logged sporadically by local inhabitants and selectively by timber companies BSEF became a protected forest in 1979. In East Kalimantan, an unusually prolonged and severe drought lasted from June 1982 until April 1983. It was linked to a strong El Nino Southern Oscillation (ENSO) event. Another strong ENSO event occurred in 1997 and extended into 1998. In the two rainless periods of 1982-83 and 1997-98, huge areas of rain forest in East Kalimantan, including the BSEF, were affected by droughts and by drought-related fires (Kobayashi *et al.* 1999).

Fourteen dead and living trees of various species and diameters in the burnt area were cut down (Table 1). The macro- and microscopic investigation was focused on the cross section and longitudinal surface of the basal part of trunk. The terminology used follows the International Association of Wood Anatomists' Standard (Wheeler *et al.* 1989). All defects caused by biological attack and physical deterioration on the wood disc were recorded, and the percentage of decayed area measured by the dot-grid method. Significant abnormalities were photographed and analysed. Microscopical features were observed on prepared slides 25-30 µm thick and the solid wood samples examined under light- and stereo-microscopes.

RESULTS AND DISCUSSION

General Condition and Type of Trees After the Fire

Although the death of trees very much depended on thermal radiation intensity, almost all small diameter trees (up to 10 cm) were highly susceptible to fire damage. The bark peeled and the stem split in some of them. Generally the impact of fire on trees depends on tree height and diameter, type of leaf and bark, and heat resistance of sap- and heartwood. Almost all woody plants were destroyed in the area. The burned trees could be classified into four groups:

- *Burnt and dead:* These trees were common in the area (Photo 1).
- *Dying*: Many trees were in this condition, shedding their leaves and their branches drying out (Photo 2).
- *Stressed*: After all leaves were shed over some months, then new buds sprout on the branches and the base of tree (Photo 3).
- *Fire-resistant*: This condition was found especially for the tall trees, high wood density, isolated trees. They have thicker bark which contains sclerenchyma and in general have few shrubs and/or litter around them (Photo 4).

Responses of Wood to Forest Fire

The principal response of wood to thermal radiation is to change vessel formation and fibre dimensions, create more excretion cells, and

Photo 1. Dead trees in the forest

Photo 2. Trees shedding their leaves after the fire

Photo 4. The fire resistant *Shorea ovalis*

Photo 3. Sprouting after fire injury

Table 1. General description of wood anatomy and morphology in burnt trees at Bukit Soeharto National Park

No	Genus/ Family	ø (cm)	Thick-ness of bark (cm)	Density (g cm^{-3})	Tree condi-tion	Damage type								Remarks
						Splits	Hollows	Side burnt	Discolou-ration	Blue stain and other fungi	Moulted area %	Decayed	Insect attack	
1.	Meranti merah (I) *Shorea* spp) Dipterocarpaceae	58	0.90	0.56	live	split from heart to cambium	not found	only in bark (light)	at heatwood (not blue stain)	not found	-	not found	not found	
2.	Meranti merah (II) (*Shorea* spp) Dipterocarpaceae	25.5	0.60	0.56	dead	not found	big circle enough	not found	not found	little	-	at all hollow areas	not found	calluses formed
3.	Bangkirai (I) (*Shorea laevis*) Dipterocarpaceae	44	0.85	0.91	live	not found	big circle enough (moat)	only in bark (light), not through inside wood	not found	not found	-	Some at hollow area and split areas	not found	calluses formed from post-fire in 1982 and protecting the wood from fire activity at years 97
4.	Bangkirai (II) (*Shorea laevis*) Dipterocarpaceae	69	0.85	0.91	live	splitted from pith to heartwood and becoe discolour-ation	circled	really bad (charcoal formed) at opening wood uncovered bark)	at around opening wood part since earlier '82	A little present	-	A little at sapwood post- fire in 1982	not found	calluses formed since first fire, make wood become misshapen
5.	Jabon (*Anthocephalus cadamba*) Rubiaceae	38.5	0.50	0.36	dead	split/crack because of bend when it fell down	not found	bark burnt but not through inside wood	all over wood parts (heartwood and sapwood)	all over wood parts (heartwood and sapwood)	>75% (sapwood and heartwood)	Decay all over wood can be seen after planing	found pinhole	discolouration at heartwood from dark to light brown
6.	Simpur (*Dillenia exelsa*) Dilleniaceae	26.5	0.75	0.80	live	not found	not found	not found	not found	not found (normal)	-	A little at sapwood	not found	

Table 1. (*continued*)

No	Genus/ Family	ø (cm)	Thick-ness of bark (cm)	Density (g cm^{-3})	Tree condi-tion	Damage type								Remarks
						Splits	Hollows	Side burnt	Discolou-ration	Blue stain and other fungi	Moulted area %	Decayed	Insect attack	
7.	Medang (*Notaphoebe* spp./*Litsea* spp.) Lauraceae	31	1,1	0,64	dead	A little splitting at heart	not found	in bark parts not bad damage	all over sapwood	at opening bark found white spots in the periphery of wood because of borer	<10% outer sapwood parts	from bark to sapwood	found big gap of pinhole borer at sapwood and	
8.	Akasia (*Acacia mangium*) Leguminosae	22.5	0.35	0.65	dead	not found	not found	not found but having a high water deficiency	at sapwood but heartwood still good	at sapwood around stem	<20% sapwood part	all over sapwood parts	tunnel attack	heartwood still good
9.	Mata buaya *Endospermum deadenum* Euphorbiaceae	24	0,25	0.50	dead	cracked lines (short) from heart to cambium	not found	not found	dark, heavy brown, black spots	the whole wood/ sporadic (in heart-wood and sapwood) and marked with brown lines	>80% sapwood heartwood	along part from pith to cambium, founded the sapwood totally damaged, marked on after planing	too much pinhole	the wood very susceptible, less than one year, and then die in the field
10.	Leda (*Eucalyptus deglupta*) Myrtaceae	21.25	0.10	0.79	dead	found, in short formed (during drying proccess)	not found	almost surrounding the stems to sapwood	does not appear	not found	-	a litle bit in the burnt area	not found	sapwood or heartwood are very susceptible although the bark was peeled
11.	Sengon (*Paraserianthes falcataria*) Leguminosae	50	0.35	0.46	dead	found from heart to cambium split	not found	not found	discolouration in all sapwood surrounding the stems (blackish brown)	fungi attack (not blue stain) causing discolouration, with brownish lines	>75% sapwood and heartwood	all sapwood up to a little at heartwood	much borer making smaller tunnels than in acacia and medang	

Table 1. (*continued*)

No	Genus/ Family	ø (cm)	Thick-ness of bark (cm)	Density (g cm^{-3})	Tree condi-tion	Damage type								Remarks
						Splits	Hollows	Side burnt	Discolou-ration	Blue stain and other fungi	Moulted area %	Decayed	Insect attack	
12.	Terap (*Artocarpus elastica*) Moraceae	41	0.70	0.60	live	a little	not found	not found	not found (normal)	not found	<5% outer part of sapwood	a little	found at rotten area	
13.	Ulin *(Eusideroxylon zwageri)* Lauraceae)	60	0.80	1.1	live	-	-	outer parts of bark	-	-	-	-	-	decreased cell production
14.	Merkubung *(Macaranga gigantea)* Euphorbiaceae	50	0.35	0.45	dead	split vertically and dead	-	extinguish and peeled	all wood from inside to outside	badly	> 75% sapwood and heartwood	rapidly from the bottom of trees	many borers	very susceptible population

produce abnormalities in shape/form of trees. According to macroscopic and microscopic investigations, the abnormalities in wood or trees vary depending on the species and the burning process and the reaction can be generally classified into following responses:

The wood forms the smaller pores but they are packed more densely than normal wood

The ability of wood to adapt to their circumstances has been basically decided by the tree's genetic make up. One way to adjust to water deficiency is to have smaller diameter pores in xylem. This may help respiration through stronger transportation by improved capillary power. On the other hand, holocellulose production is reduced much less under water-deficient conditions. Big trees, such as ulin (*Eusideroxylon zwageri*), red meranti (*Shorea* sp.) and medang (*Notaphoebe* sp.), especially can withstand fire and easily compete with other trees in the dry season, because this group has higher crowns and deeper root systems. This phenomenon can be seen also in trees from arid or semiarid areas, e.g. *Bumelia lanuginosa* and *Manilkara* spp. (Kukachka 1980, 1981 in Carlquist 1987) with changing their shape and arrangement of pores. The pores become smaller, denser and clustered with many tracheids surrounding them.

Changes in dimension and numbers of axial parenchyma

If the trees are stressed, they reduce production of cells and form them more densely. After a while, the new cells become larger and rich in axial parenchyma as there is less competition due to the deaths of surrounding trees and greater availability of nutrients from the burnt trees. This was observed in the large buttresses of *Irvingia* sp. (bongin) (Photo 6).

Producing more axial intercellular canals

Severe drought stimulated the excretion cells to produce much gum. This could be due to the intensive formation of axial intercellular canals, in the shape of concentric tangential bands. Bangkirai generally produces resin when the axial canals become dense (Photo 7).

Expanding decay in the wood

The process of decay begins from lack of water when water content is reduced below the fibre saturation point, especially in sapwood. This condition may let fungi invade the outside parenchyma cells through splits in the bark or lenticels. Fungal enzymes can degrade the cell wall and then the wood deteriorates continuously, e.g. kenuar (*Shorea johorensis*) (Photo 10).

Photo 5. The concentric line from abnormal cells, the pores smaller and denser in red meranti (*Shorea* sp.)

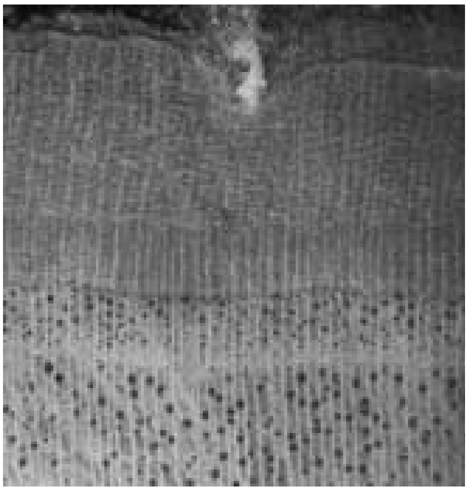
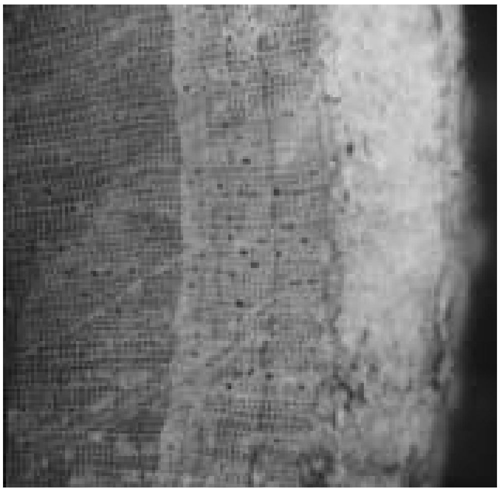


Photo 6. Dimension and intensity change of axial parenchyma in bongin (*Irvingia* sp.)



Creating a ring of fibres or delaying of pore formation

Trees produced more thick fibres than pore cells to increase the efficiency of water and nutrient uptake. This phenomenon is controlled by gibberelin synthesising enzymes (Guenter and Hartmut 1983). The fibre tissue dominates in tangential lines, e.g. simpur (*Dillenia exelsa*) (Photo 9).

Photo 7. The dense tangential line of axial intercellular canals in bangkirai (*Shorea laevis*)

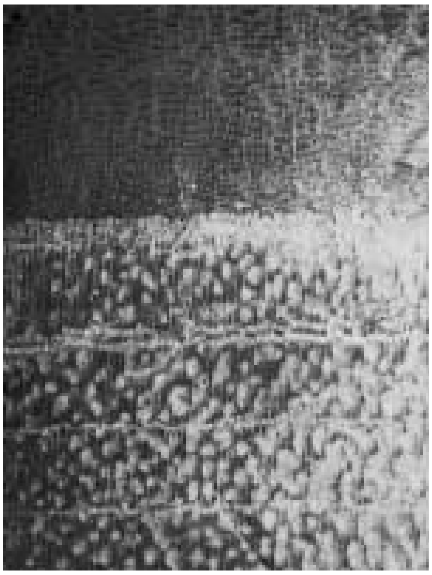


Photo 8. Decayed spots in the wood tissue in bangkirai (*Shorea laevis*)

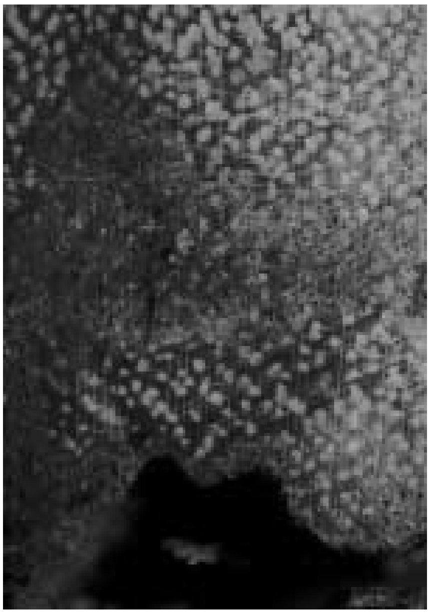


Photo 9. Concentrated fibres in a concentric pattern in *Dillenia exelsa*

Photo 10. Bole becoming hollow in kenuar (*Shorea johorensis)*

Creating new calluses and producing a misshapen bole

Calluses grow rapidly both sides of damaged bark to cover the wound and this concentrated growth activity results in a misshapen bole (Photo 11).

Producing gums and other abnormal components

A large quantity of gum is needed to cover injuries and contribute to new tissue called the "barrier zone" (Shigo 1989). The cambium takes several years to cover the damaged tissue and a lot of resin or gum is trapped in the wood. An example of gum occurring around the wood causing a ring-hollow pattern in kenuar (*Shorea johorensis*) is shown in Photo 12.

Bole becomes hollow

Sometime calluses cannot quickly close the wound and this condition attracts fungi, bacteria or other pathogens which decompose the wood cells and allow further development of fungal or insect attack. Then the wound becomes deeper and the bole hollow.

Photo 11. The misshapen of bole of bangkirai (*Shorea laevis*)

Photo 12. Trapped resins inside wood cells of kenuar (*Shorea johorensis*)

TYPES OF WOOD DETERIORATION AFTER FIRE

The research indicated that the state of the wood was largely influenced by post-fire deterioration, such as the effects of fungi, bacteria and insect invasions rather than by fire itself. The effects varied depending on durability and other wood properties. The thin cells and light coloured wood usually have less extractive toxin and this wood was very susceptible to damage. Trees were classified into four groups according the type of post-fire damage:

Merkubung/Sengon (Type 1)

This type has low durability. Generally wood density is low and the wood light coloured with no difference between sapwood and heartwood. Cell walls are thin so can be easily penetrated by fungal hyphae. Normally, blue-stain or other fungi can reach more than two-thirds of the bole within one-year (Photo 13). The stem base in contact with the ground decays severely and the stem is easily blown over. Sengon (*Paraserianthes falcataria*) and some other pioneer species are typical of this group.

Akasia/Medang (Type 2)

In this group, sapwood and heartwood are distinct and have different moisture content and extractives. The sapwood, which has not many extractives, is a good place for microorganism infection when exposed by fire damage but the heartwood is resistant to attack (Photo 14). In this type, one year after fire, the sapwood has already badly decayed while the heartwood is still sound. More investigation of mechanical properties is needed if the heartwood is to be utilised.

Photo 13. Fungi rapidly attack the entire disk of merkubung (*Macaranga gigantea*) tree (Type I)

Photo 14. Fungi attacking only sapwood and followed by insect borers in heartwood of medang (*Litsea* sp.) (Type II)

Ulin/Bangkirai (Type 3*)*

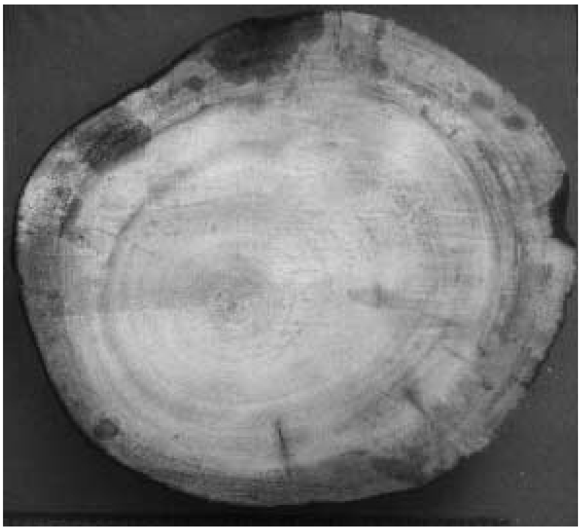
This type has medium and high wood density. The bark is thick and contains much fibre and sclerenchyma. The fire usually only burnt the outer bark, but when exposed to high thermal radiation for a long period the cambium activity stopped for some time. Wood with an abnormal structure is produced. The bark remains on the cambium after its death and there are no places for microorganisms to attack (Photo 15). Ironwood (*Diospyros* sp.) made smaller pores and the cell reproduce slowly. Some other species e.g. meranti batu (*Shorea* sp.) show abnormal growth and produce more gum than usual. One-year after the by forest fire this group had normal wood quality, even in dead trees.

Photo 15. High density dark red meranti (*Shorea* sp.) with thick and compact bark which is very resistant to fire and microorganisms (Type III)

Leda/Palawan (Type 4)

The last group type is leda (*Eucalyptus deglupta*) and palawan (*Tristania* sp.). These trees usually have thin bark, often shed in strips, so sunlight can reach the wood surface. This is a reason wood is durable and more resistant to invasion by fungi and insects (Photo 16). This wood is not good for pulping as the remaining charcoal will cause discolouration.

Photo 16. The sound stem disk in leda (*Eucalyptus deglupta*) after fire with only in the outside of the bole charcoaled (Type IV)



CONCLUSIONS

- The response of wood to thermal radiation is manifested in the formation of vessels, change of fibre dimensions, stimulation of excretion cells and bole shape abnormalities.
- Impact of fire on trees was variable depending on height and diameter of the tree, type of leaf and bark, and resistance of sapwood and heartwood.
- The state of the wood in the trees was more influenced by post-fire deterioration, such as invasion by fungi, bacteria and insects rather than by fire itself. The extent of these influences on wood quality was determined by the durability and other wood properties

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Evaluation of Forest Harvesting Impacts on Forest Ecosystems

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Abstract

In the Guarani preservation area 100 ha of forest land was cut to evaluate harvest impact in natural subtropical forest. Two treatments were applied: “commercial logging” in which the logging contractor works in the traditional way, and “improved harvest” in which trees are selected and the skidding trails and landings planned. Forest structure and composition, seedlings and regeneration; and soil physical parameters such as soil density, penetration resistance were measured before harvesting. The trees were cut by chainsaw and moved by a rubber tyred skidder to the landing area for loading on a truck. After harvesting, damage by cutting and by skidding was measured. All previous parameters were re-measured and traffic intensity in each plot calculated. The harvest yields were 9.9 m^3 ha^{-1} for the improved harvesting and 16.4 m^3 ha^{-1} for the commercial treatment. Trees felled were 6.8 trees ha^{-1} for improved harvest and 9.9 trees ha^{-1} for the commercial harvest. For canopy trees, commercial harvesting reduced the initial dominance 19.3%, while improved harvesting only decreased it 9.5% so forest structure is less affected by the improved harvesting. There was little change in abundance and species composition. Changes were observed in the order of importance of some species, e.g. *Parapiptademia rigida* was replaced by species of lesser importance. Regeneration after the commercial harvesting was less than in the improved harvesting method. Commercial harvesting had more (60%) traffic intensity (Mg km^{-1} ha^{-1}) along all the skid trials in the plots.

INTRODUCTION

As in many neotropical regions, selective tree logging is a traditionally used to harvest timber in Misiones Province, Argentina. Gaps in the forest are usually an important consequence for the forest dynamics and their magnitude can determine the level of changes in the floristic composition (Delgado 1995). This kind of harvesting can create gaps, but if done in a large scale it can alter the nature of the original forest. Timber harvesting affects forest ecosystems in various ways, e.g. site degradation, reduction of forest water supply, soil loss and green gas emissions (Kobayashi 1994).

The impacts of traditional logging on the Misiones forest ecosystem have not been studied, a situation common in many regions with neotropical forests (Kammerscheidt and Torres Lezama 1997). The wisest strategy for maintaining integrity of the tropical forests is to develop management techniques which promote a mix of timber and non

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timber products for present and future human populations (McNabb *et al.* 1997). However, successful creation and implementation of sustainable management of tropical forest ecosystems is partially dependent on the development of forest operations which are compatible with the sustainable concept (Dykstra and Heinrich 1992).

Regarding impacts of harvesting systems on natural regeneration, several studies have focused specifically on what happens in the medium and long term. One of the most studied effects is the change of floristic composition in the regenerating forest. Wagner (1997) found in a humid premontane forest of Costa Rica that the timber management changed floristic composition at the level of life kinds, families and species. These changes were still present 14 years after harvesting concluded.

It is estimated that after forest harvesting the growth and regeneration is reduced by degradation of natural forest, erosion, landslides and greenhouse effects (Kobayashi 1994). Forest harvesting affects forest structure. The density of standing trees decreases after harvesting, but size class distribution reveals a similar pattern to the forest structure before harvesting, because large trees, more than 60 cm diameter of breast height (dbh) are felled and small sized trees are either removed or dead. (Kobayashi 1994). The effects on canopy opening by harvesting can be much higher than opening by natural tree mortality in forests without management (Delgado 1997) and could have remarkable positive effects on heliophile species and less notable or even negative effects on tolerant species (Wagner 1997). In some cases, even heliophile plants could regenerate less because of proliferation of bamboos and lianas (Guariguata 1998) after canopy opening.

Studies on forest structure allow a quantitative inventory of species constituting the community, and also inferences on its history with regard to dynamics and future tendencies (López *et al.* 1996). Some authors such as Lamprecht (1990), Contente (1986), Delgado (1995) and López *et al.* (1996) have used structural parameters such as dominance, abundance frequency and an importance value index (IVI) for analysis of forest structure. Kammesheidt and Torres-Lezama (1997) have studied selective harvesting impact on structure and spatial distribution of commercial tree species in a deciduous humid forest in Venezuela and found that one species totally disappeared and two other species were almost eliminated. The amount of damage and knowledge of the forest reaction caused by harvesting impacts are needed to evaluate the future production of the forest (Finegan 1995). In a study on the effects of timber management on floristic biodiversity and the structure of humid premountainous forests in Costa Rica, Wagner (1997) found out that the harvesting caused a reduction of the number of tree species with dbh over 10 cm. In the same forest, without harvesting, the basal area of commercial species (dbh over 60 cm) was 23 m^2 ha^{-1} out of a total basal area of 33 m^2 ha^{-1} and 60% of timber yielding trees were cut. Harvesting affected 6-10% of the total area. Kobayashi (1994) suggests that for tropical forest, selective cutting damages more than 55% of the remaining standing trees. In a tropical Venezuelan forest harvested at a rate of 10 trees ha^{-1} an average of 30% of trees were damaged (Kammesheidt and Torres-Lezama 1997).

In Scandinavia the range of total area disturbed by machinery in the thinning operations is about 15-30% (Wasterlund 1992). A Costa Rican tropical forest cut at a rate of 16.5 m^3 ha^{-1} and logged with crawled tractors had 6-10% of total area damaged (Wagner 1997). Greacen and Sands (1980) reviewed causes and effects of forest soil compaction and reported that log skidding affected the soils of skid trails to a depth of 300 mm, and the soil under a logging road was compacted to a depth of 500 mm. Schafer *et al.* (1989) stated that soil is compacted when a force system exceeds the soil strength. Despite experience that has demonstrated the stress-strain behaviour of agricultural soils as complex and difficult to describe, Raper *et al.* (1994) quoted several researchers assuming for tyre-induced soil compaction that the stress with more impact on soil depth is vertical instead of other directions. The risk of subsoil compaction due to vehicle traffic is mainly determined by the wheel load even when the ground contact pressure is extremely low (Smith and Dickson 1990). They quoted examples of compaction occurring below 400 mm as a result of axle loads greater than 6.0 Mg and in one case compaction occurred below 1 m due to the passage of a vehicle with a pressure of only 100 kPa but having an extremely large axle load. They also established that compaction occurring below 500 mm depth as a result of axle loads greater than 10 Mg can last for 7 years or more. There is little known about the magnitude and duration of shifts in soil properties within openings with no disturbance compared to those with traffic (McNabb *et al.* 1997).

MATERIALS AND METHODS

The survey was carried out at the Guaraní preservation area, 5343 ha of untouched subtropical forest and part of a large biosphere preservation zone called Yaboti. The forest belongs to the National University of Misiones, Misiones Province, Argentina. The location is at 25º 56' S latitude, 54º 15' W longitude. The experimental land has a mountainous landscape with steep slopes. The highest point is 574 m asl in the southern sector. The land is lower to the southwest and averages 180-200 m. Soils of Guarani belong to the cartofigure complex known locally as 6a y 6b, according to the USDA taxonomy; the most important soils are Haplortoxes, Kaniudults, Kandihunults, Umbracualfs, Hapludalfs, Kandiudalfs, Argiudoles, Hapludoles, Haplumbrepts, Distrocrepts, and Udortents. The climate in Misiones is subtropical without a dry season and some frost in winter. The highest temperature recorded is 39ºC and the lowest -6ºC, the average annual rainfall is 1800 mm.

In this area, 60 ha were harvested with two treatments in a total area of 100 ha. The treatments were Improved Harvesting Method (IHM), Commercial Harvesting Method (CHM) and control (CP). Details of the IHM are:

- the trees to be cut are chosen according to a standard for dbh and species, health and quality of the stem, and presence of seedlings (at least one of each species to be left in the area); and
- in the selected areas, the distance to be passed over by the machine in the plots and, skid trails are established and the timber yard located. Allowable traffic intensities for each plot sector are specified.

In the commercial harvesting treatment the logging contractor selects the individual trees to be cut and establishes timber transportation distances and timber yard within each plot. The control plots have no tree felling and no machine traffic.

The treatment plots were 200 m x 200 m, with a central control plot of 100 m x 100 m in each, distributed with at least 2 replications for each block and in 3 different topofigure conditions, high plain, steep slope and low plain. In each block, one treatment per plot was assigned to have a total of 3 control plots, six CHM and nine IHM. The location of these plots follows statistical standards they were arranged according the possibilities offered by the landscape. An effort was made to separate plots for CHM to avoid major damage to the environment. The following data was obtained in the central part of each plot (Table 1):

- damaged tree species, mortality and forest type,
- soil compactation through penetration resistance (ASAE N313.4, 1994) and bulk density before and after harvesting,
- forest structure and composition for each harvesting treatment and control area,
- forest regeneration.

The study area had the original subtropical forest vegetation, which has different layers containing a great diversity of vegetation caracterised by trees, shrubs, bamboos, ferns, climbing plants and epiphytes. The area belongs to the Amazonian dominium, Parana Province, mixed forest district. This area has 89 tree species in 30 families, mainly Leguminosae (19.1%), Lauraceae (6.7%), Euphorbiaceae (5.6%), Rutaceae (5.6%) and Myrtaceae (5.6%), Sapindaceae (4.5%), Boraginaceae (4.5%) and

Table 1. Measurements' summary

Treatments	Topography	Replications	Plot no. used	Measurements	Plot name
IHM	High plain	3	2,3 6	All[1] Soils, traffic	IHM-1, IHM-2 IHM-3
	Slope	3	8	Soils, traffic	IHM-4
	Low plain				
CHM	High plain	3	1,C	All	CHM-1, CHM-2
	Slope	2	7,9	Soil, traffic	CHM-4,CHM-5
	Low plain	2			
CP	High plain	1	4	All	CP-1
	Slope	1			
	Low plain	1			

[1] See list of data recorded in above text.

Meliaceae (4.5%). The species with the high ecological importance value (EIV) were *Ocotea puberula, O. dyospirifolia, Prunus subcoriacea, Lonchocarpus leucanthus, Nectandra saligna* and *Parapiptademia rígida* (Lopez *et al.* 1996). It can be inferred that the community is a mature forest because the species with high EIV are characteristic of advanced successional stages.

The average absolute dominance value is 23.9 m^2 ha^{-1} with a range 17.7-29.8 m^2 ha^{-1}. The average density is of 282 trees ha^{-1}, ranging between 174 and 379 trees ha^{-1}.The forest structure characteristics were calculated by the method of Lòpez *et al.* (1996). This work used abundance, dominance, and frequency as structure parameters. All these parameters can be calculated in an absolute and relative way before and after felling for all plots. Each of these parameters for the ten most important species have been compared. Various plots were damaged by a tornado in September 1998. Since the effect of this phenomenon could mask the effect of harvesting, it was considered appropiate to count trees which were blown over by the tornado and register them as alive to compare treatments.

A systematic sampling system was used for regeneration measurement, with rectangular plots 20 m^2 for natural regeneration of classes 1,2,3 (see below) and of 60 m^2 for class 4. In each effective measured hectare, 5 sampling units of two sizes were installed to evaluate regeneration of all the tree species. Sampling intensities were 1% for the size classes of 1-3 and 3% for class 4. So the sampled area in each plot for the first 3 classes was 100 m^2 and for the class 4, 300 m^2. The recorded variables in each sampling unit before and after harvesting were:

- name of species,
- main vegetation under the trees (bamboos, ferns, etc),
- height class of (1,2,3,4). The individuals regenerated were classified in the following height classes (Montagnini *et al.* 1998): class 1 - individuals 30-49.9 cm, class 2 – 50-149 cm, class 3 – 150-299 cm, class 4 - above 300 cm height and 10 cm dbh.

These size classes were used to distinguish between seedlings (30-150 cm height) and for saplings (150 cm height and to 10 cm dbh) (Hutchinson 1993, Quiros and Finegan 1998).

Damage to remaining trees in the forest was recorded according the methodology of Bertault and Sist (1997). The classification used the source of injury (felling and skidding), and the part of the tree affected (Table 2). This work was carried out in the sample plots and this allowed indentification of damaged trees.

The number of damaged trees in each category was obtained. These data were classified

Table 2. Damage classification system for trees over 10 cm dbh

Major crown injury/felling
Major crown injury/skidding
Slight and moderate crown injury/felling
Slight and moderate crown injury/skidding
Broken crown /felling
Broken crown/skidding
Broken trunk/skidding
Broken trunk/felling
Uprooted-felling
Uprooted-skidding
Bark and wood damage/skidding
Bark and wood damage/felling

by the four diameter classes with regard to the initial tree number ha^{-1} and these values were grouped for each treatment and each plot.

The harvesting was carried out June-July 1999, so the entire area had the same environmental conditions (temperature, rain and light). The trees were cut by chainsaw (Stihl 070), and logged with a rubber tyred skidder of 10 tons and 140 cv power engine. The skidder loaded the truck in the landing area. The length of the tracks of each section used at the time of extraction by the skidder was mapped to measure the traffic density. The number of times of tractor passed and the weight of the load for each passage were recorded. The latter was estimated from the log pieces at loading time. From these measurements, the value of Mg km^{-1} ha^{-1} was obtained for each plot and treatment.

The penetration resistance was measured by an electronic cone penetrometer (ASAE S313.94, ASAE 1994). Measurements were made in the rut of the skidder and in the almost untouched forest. The traffic intensity was: Intensity 1 for one to six passes of the skidder and logs; Intensity 2 for seven to twelve passes, and Intensity 3 for more than thirteen passes.

RESULTS AND DISCUSSION

The results show that the timber volume harvested from CHM was 65.7% more than that from IHM (Table 3). This difference in harvesting was also shown in number of trees (46.3%) and species (12.2%).

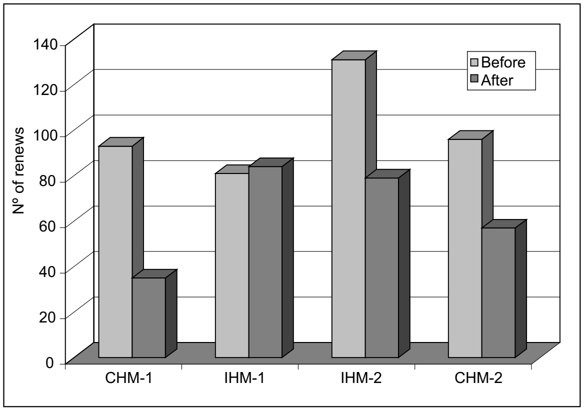
The densities of seedlings and saplings found in the four plots before timber harvesting were between 8333 and 13 366 plants ha^{-1}. These figures reached 64% of the regeneration (including the palms) found by Wagner (1997) in a humid premontane forest in Costa Rica.

The effect of the two harvesting systems on the regeneration number in the sample plots is shown in the Fig. 1. The frequencies shown include individuals damaged by harvesting.

Table 3. Harvesting results for volume and number of trees and species

Treatments	IHM-1	IHM-2	Total	CHM-1	CHM-2	Total
	Timber volume harvested (m^3 ha^{-1})					
Before treatment	567.6	477.9	1.045.5	495.4	410.8	906.2
Harvest	34.4	45.0	79.4	59.8	71.7	131.5
After treatment	533.3	432.8	966.1	435.5	339.1	774.6
	Number of trees (no.ha^{-1})					
Before treatment	292	229	521	253	197	450
Harvest	24	30	54	36	43	79
After treatment	268	199	467	217	154	371
	Number of species (no.ha^{-1})					
Before treatment	48	47	65	53	51	74
Harvest	5	8	10	8	7	8
After treatment	48	47	65	52	51	74

Figure 1. Number of regeneration plants before and after timber harvesting in plots 1 and 2 for CMH and IHM treatments



Regeneration mortality in plot CHM-2 due to harvesting damage was 53% and in CHM-1 it was 58%. These results are similar to the determination of Guariguata (1998) who referred to the direct impact of harvesting procedures on the remnant mass. In the two IHM plots there were less plants lost than in the CHM plots. In IHM-1 there was no loss of second growth plants at all and a recruitment of 2% after harvesting. In this plot, no damage to second growth plants was registered. In plot IHM-2 the effect of harvesting was more serious than in IHM-1, with a mortality rate of 37% and damage to second growth plants lower than 5%.

The harvesting had a major impact on the seedlings (size classes 1 and 2). Kammesheidt *et al.* (1997) and Saenz (1996) pointed out the lack of detailed information on damage caused by different harvesting methods and this makes it difficult to compare our results with others from similar forests. In all plots, only a reduction of natural regeneration was detected as a direct effect of the harvesting and no change in regeneration composition has been detected yet, due to the canopy opening. This can be explained mainly by the fact that the changes often do not occur immediately but can persist for a long time after harvesting, as asserted by Wagner (1997). An evaluation of changes in the structure and composition of the remnant mass produced by harvesting is nevertheless essential.

Total values of structural parameters of the forest in each treatment before and after felling are shown in Table 4.

The structure is less affected by the IHM treatment as in the commercial treatment a reduction of 19.3% in initial dominance occurred but in IHM this value was only 9.5%, (Table 4 and Fig. 2). This result agrees with Sorianegara (1978) and Kartawinata (1978) in Delgado (1995) who affirm that harvesting has similar results on gap formation but in a higher proportion, and this effect could be increased not only by felling intensity but also by procedures used in harvesting.

The most represented species for each treatment and parameter have been analysed (Table 5). The species have changed their positions but the most abundant species are still the same ten. It can be observed that *Parapiptadenia rígida* loses its position. There is a change of range but not of species.

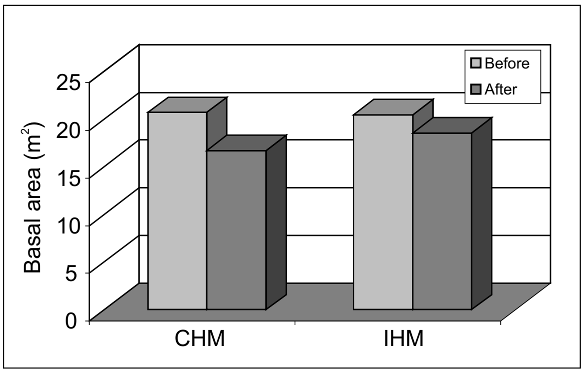
Table 4. Total values ($m^2 ha^{-1}$) of structural parameters in each harvesting treatment

	CHM		IHM	
	Before felling	After felling	Before felling	After felling
	($m^2 ha^{-1}$)			
Dominance	20.7	16.7	20.5	18.5
	(number of trees ha^{-1})			
Abundance	197	186	230	220

Table 5. Dominance values before and after felling for both treatments

Commercial harvesting treatment				Improved harvesting treatment			
Before		After		Before		After	
Species	Dominance (m^2 ha^{-1})	Species	Dominance (m^2 ha^{-1})	Species	Dominance (m^2 ha^{-1})	Species	Dominance (m^2 ha^{-1})
Luhea divaricata SC	4.4	SC	2.3	AC	2.2	G	1.7
Patagonula americana GB	2.5	GB	2.1	SC	1.9	AC	1.4
Apuleia leiocarpa GR	1.8	GR	1.4	G	1.7	SC	1.2
Balforoudendron redelianum G	1.4	G	1.4	C	1.2	C	1.2
Helietta apiculata IO	1.2	IO	1.1	VS	1.1	VS	1.1
Lonchocarpus leuchantus RI	0.8	LY	0.7	GR	1.0	PD	0.8
Ocotea diospirifolia LY	0.7	RI	0.7	PD	0.8	PV	0.8
Cedrela fissilis C	0.6	C	0.6	PV	0.8	GB	0.8
Tabeuia pulcherrima LPI	0.6	VS	0.6	GB	0.8	GR	0.7
Chrysophillum marginatum VS	0.6	LN	0.5	IO	0.7	IO	0.7
Others	6.1	Others	5.5	Others	8.0	Others	8.0
Total	20.7	Total	16.7	Total	20.3	Total	18.5

Figure 2. Total dominance values



No variations in floristic composition were registered beyond changes in their dominance or abundance. No species was lost in any of the treatments. This result conflicts with that of Kammesheidt *et al.* (1997) who worked in a humid deciduous forest in Venezuela with a highly selective harvesting system. They reported a total disappearance of some species after various harvesting cycles. It is noteworthy that in this study none of the harvesting systems used is highly selective nor is the time interval that has elapsed comparable. However, Wagner (1997) studying a premontane humid forest in Costa Rica, reached similar conclusions to Kammesheidt *et al.* (1997).

Even if no important variations in the floristic composition were found, it is necessary to wait for the evolution of the forest. According to Finegan (1995), the relationship to the openings made by the intervention should take into account what is actually conserved in a managed forest. Delgado (1995) makes the statement that these changes and processes do not usually occur immediately.

In general in the analysed plots there are fewer remaining trees damaged by harvesting in those plots with the IHM treatment than in those with CHM treatment (Table 6). If the percentage of damaged trees is divided by the quantity of trees extracted per hectare, differences between treatments is maintained and the IHM shows less trees damaged than the CHM (Table 7). The most serious damage was concentrated in the lower diameter classes (Table 6). This is in accordance with Arango (1998) and Kammesheidt *et al.* (1997) since the smallest suffer more from the impacts of trees during felling and logs skidding.

Table 6. Type and number of trees damaged by the logging treatments

Type of damage	CHM			IHM		
	Average number of damaged trees ha^{-1}					
Diameter class	29.9	49.9	69.9	29.9	49.9	69.9
Major crown injury/felling	0.50	0.33	0,167	-	-	-
Major crown injury/skidding	1.17	1.17	0.333	0.56	0.44	-
Slight and moderate crown injury/felling	1.17	0.17	0.167	0.67	-	-
Slight and moderate crown injury/skidding	0.17	-	-	-	-	-
Broken crown /felling	0.50	-	-	0.56	0.22	0.11
Broken crown /skidding	0.17	-	-	-	-	-
Broken trunk/skidding	4.50	1.33	0.167	-	-	-
Broken trunk/ felling	1.83	-	-	2.11	0.78	0.11
Uprooted-felling	1.83	1.17	-	0.67	-	0.11
Uprooted-skidding	-	-	-	-	-	-
Bark and wood damage/skidding	1.50	1.00	0.167	1.22	0.22	-
Bark and wood damage/felling	0.67	0.17	-	0.56	0.22	0.22

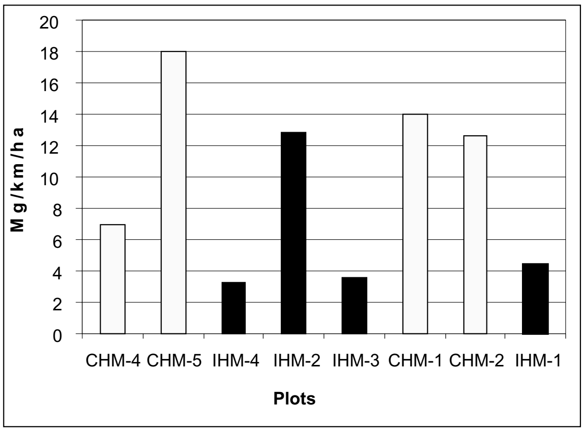
Table 7. Relation between damaged trees and harvested trees

Plots	Total trees	Damaged	Harvested trees
CHM-1	253	21	9
CHM-2	197	14	7
IHM-1	292	7	3
IHM-2	229	13	10

The lack of experience in this type of harvesting in the region suggests a comparison of traffic intensity values would be useful. Traffic density values between 3.5 Mg km^{-1} ha^{-1} and 18 Mg km^{-1} ha^{-1} were obtained, depending much upon the harvesting intensity. In the low intensity IHM it was 6.0 Mg km^{-1} ha^{-1} and in CHM it was 12.9 Mg km^{-1} ha^{-1}. The area disturbed by the treatments was CHM 679 $m^2 ha^{-1}$ (6.8% ha^{-1}), and IHM 508 $m^2 ha^{-1}$ (5.1% ha^{-1}) and the road 4554 $m^2 ha^{-1}$.

As the felled volumes were not uniformly distributed in each plot, and this was not a criterion for the treatment assignment, a comparison of traffic intensity with harvesting volumes in each plot was carried out (Fig. 3). The plots that had a commercial treatment were those with the highest traffic intensities per cubic metre of extracted wood.

Figure 3. Traffic intensity for each extracted cubic metre of wood



In Table 8, values of penetration resistance to a soil depth of 600 mm are presented obtained from the traffic and no traffic zones, according to intensity categories described in the methodology. The higher the traffic intensity the greater was the penetration resistance at all depths. The other intensities (1 and 2) have a significant difference to 100 mm depth and then no difference between these two groups. It is not clear why there was no difference between intensity 1 and 2 below 100 mm. Overall, these results agree with Smith and

Table 8. Penetration resistance in relation to soil depth and traffic intensity

Traffic intensity	Soil depth (mm)									
	25	50	100	150	200	250	300	400	500	600
	Penetration resistance values (Mpa)									
0	0.43 a	0.63 a	0.91 a	1.14 a	1.27 a	1.47 a	1.60 a	1.91 a	2.12abc	2.34 a
1	0.72 b	0.96 b	1.15 b	1.23 a	1.39 a	1.49 a	1.58 a	1.77 a	2.08 ab	2.22 a
2	0.88 b	1.03 b	1.13ab	1.22 a	1.45 a	1.62 a	1.66 a	1.82 a	1.95 a	2.11 a
3	1.24 c	1.46 c	1.61 c	1.77 b	1.98 b	2.04 b	2.11 b	2.24 b	2.39 bc	2.68 b

Values with different letters are significantly different from each other (p = 0.05)

Table 9. Moisture content and soil depth

	Soil depth (mm)		
	50	200	450
Mean	39.3%	32.9%	35.7%
S.D	7.4%	4.0%	4.0%
N	46	47	48

Where: SD is standard deviation, and N number of samples

Dickson (1990), and Raper *et al.* (1994) report on subsoil compaction and that the greater the traffic intensity the deeper the compaction.

The bulk density results show a significant difference (p 0.01), for all intensities and to a soil depth of 500 mm (Table 10) and were in agreement with the penetration resistance results, and with expectations of soil compaction. One important point is that the bulk density values do not increase with the traffic intensities, as did penetration resistance (Table 8).

CONCLUSIONS

- The management criteria for the improved harvesting method produced less impact on the forest than the commercial harvesting.
- The improved harvesting treatment had less effect on the dominance of trees than the commercial treatment.
- No species loss or change in floristic composition occurred as a consequence of the treatments.
- An immediate effect of commercial harvesting was a substantial reduction of regeneration per hectare but was less in plots with the improved harvesting treatment.
- Seedlings were almost always more affected than saplings in both treatments.
- Traffic intensities had more effect in the comercial treatment than in the improved harvesting method.
- Compaction of surface soil and subsoil was detected at level that is a problem for both treatments.

Table 10. Bulk density for different traffic intensities and soil depth

Traffic intensities	Soil depth					
	50 mm		200 mm		450 mm	
	Control	Skid rut	Control	Skid rut	Control	Skid rut
	Bulk density (g cm^{-3})					
2 to 6 passes	0.93^{a}	1.15^{b}	1.10^{a}	1.24^{b}	1.20^{a}	1.26^{b}
8 to 12 passes	0.96^{a}	1.19^{b}	1.10^{a}	1.31^{b}	1.13^{a}	1.23^{b}
Over 13 passes	0.93^{a}	1.28^{b}	1.11^{a}	1.31^{b}	1.12^{a}	1.26^{b}

- The influence of harvesting on forest ecosystems should be determined using both medium and long-term criteria.

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8

Tree Species Composition and Above Ground Biomass of a 15-year-old Logged-over Forest at Pasoh, Negeri Sembilan, Peninsular Malaysia

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Abstract

From a study conducted in Pasoh Forest Reserve, 149 tree species in 92 genera and 38 families, all trees with a diameter breast height (dbh) of 1 cm or above were enumerated in a one hectare plot. The most abundant species was *Ficus fistulosa* across all dbh classes followed by *Monocarpia marginalis* and *Dipterocarpus cornutus*. The most diverse family was Euphorbiaceae with 25 species followed by Dipterocarpaceae (13 spp.) and Leguminosae (13 spp.). Stand density was 1951 stems ha^{-1} with Euphorbiaceae contributing about one-fifth the total number of stems. High densities of pioneer species such as *Macaranga* spp., *Vitex pinnata* and young trees of primary species, such as *Dipterocarpus* spp. and *Shorea* spp., indicate that the forest is still in an early stage of succession, yet has recovered rather well from previous disturbances, such as forest harvesting. The estimated above ground biomass was 160.8 t ha^{-1}, a reasonable value for a 15-year-old forest, also suggesting the capability of this forest to recover from previous forest harvesting.

INTRODUCTION

Basic information on species composition and plant biomass would be useful to evaluate the impact of previous forest activity. It can also indicate the capability of the forest recovering from past disturbances, so the information can be used for planning and better management of forests on a sustainable basis. If forest is to be regarded as a renewable resource, good forestry practices to prevent wastage and damage to the standing stock and the environment must be carried out during harvesting.

Biomass is defined as the total amount of living organic matter in trees and expressed in tonnes per hectare. This term is more useful as a unit of yield than volume as it allows comparisons to be made among different tree species and tree components (Brown 1997). Above ground biomass may be defined as a combination of all tree components above ground level and is important in estimating the productivity of a forest. Owing to the lack of annual rings in xylem tissues in the tropics, the biomass increment can only be estimated as the difference between two estimates of biomass at a proper time interval (Kato *et al.* 1978).

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SITE DESCRIPTION AND METHODOLOGY

Site Description

A study area of 2450 ha of forest in Compartment 121, Pasoh Forest Reserve, Negeri Sembilan, is surrounded on three sides by oil palm plantations and virgin hill dipterocarp forest on its northern boundary. The study area was selectively logged in 1984. It receives relatively high rainfall throughout the year, with a mean annual average of 2517 mm. The mean monthly temperature ranges from 24.5ϒC to 27ϒC. Soil is brownish–yellow with sandy loam clay texture of the Rengam series (Wyatt-Smith 1963).

Methodology

A 1 ha (100 m x 100 m) plot was established and further divided into 100 contiguous subplots of 10 m x 10 m. All trees of dbh of 1 cm and above were measured and identified. The above ground biomass was estimated based on the equation of Kato *et al.* (1978).

RESULTS AND DISCUSSION

Composition of Trees

A total of 149 species belonging to 92 genera and 38 families were recorded in a 1 ha plot from this forest (Table 1). The most diverse family is Euphorbiaceae (25 spp.) followed by Dipterocarpaceae (14 spp.) and Leguminosae (13 spp.). *Ficus fistulosa*, a weedy tree to 15m high, *Monocarpia marginalis*, *Dipterocarpus cornutus* and *Mallotus leucodermis* are the most numerous (Table 2). Tree density (number of trees ha^{-1}) in the ten largest families ranged from 92 to 365 with Euphorbiaceae the most common (Table 3). Comparisons with reports from other forests can be made if we restrict our calculation of diversity to trees above 10 cm dbh. The Pasoh 50 ha plot, managed by Forest Research Institute Malaysia had 210 species ha^{-1} (Kochummen *et al.* 1990). In the present study, 103 species ha^{-1} were recorded for trees greater than 10 cm dbh. This is about 50% lower density than the Pasoh 50ha plot.

Table 1. Taxonomic composition of trees 1 cm dbh and above in 1 ha plot, Pasoh Forest Reserve, Negeri Sembilan

Family	No. Genera	No. Species
Euphorbiaceae	14	25
Moraceae	3	7
Dipterocarpaceae	5	14
Leguminosae	11	13
Annonaceae	2	4
Meliaceae	2	4
Sapindaceae	3	4
Verbenaceae	3	3
Lauraceae	3	6
Rubiaceae	6	6
Fagaceae	1	2
Ebenaceae	1	3
Hypericaceae	1	2
Anacardiaceae	3	3
Lecythidaceae	1	2
Olacaceae	2	3
Myristicaceae	2	3
Melastomataceae	2	4
Myrtaceae	1	1
Polygalaceae	1	4
Sterculiaceae	3	3
Burseraceae	2	3
Tiliaceae	2	4
Elaeocarpaceae	1	3
Guttiferae	2	2
Violaceae	1	3
Ulmaceae	1	1
Rhizophoraceae	2	2
Alangiaceae	1	2
Myrsinaceae	1	2
Thymelaeaceae	1	2
Dilleniaceae	1	1
Celastraceae	2	2
Sapotaceae	1	2
Apocynaceae	1	1
Flacourtiaceae	1	1
Combretaceae	1	1
Styracaceae	1	1
	92	149

Table 2. Species Composition and density in 1 ha plot, Pasoh Forest Reserve, Negeri Sembilan

Species	No. Stems	Species	No. Stems
Ficus fistulosa	109	Cynometra ramiflora	14
Monocarpia marginalis	86	Dipterocarpus baudii	13
Dipterocarpus cornutus	84	Cinnamomum mollissimum	13
Mallotus leucodermis	70	Ficus scortechinii	13
Macaranga gigantea	55	Elaeocarpus palembanicus	12
Aglaia argentea	53	Aporusa bracteosa	12
Ficus laevis	45	Parkia speciosa	12
Vitex pinnata	39	Streblus elongatus	12
Pometia pinnata	32	Strombosia ceilanica	12
Cratoxylum formosum	31	Nephelium costatum	12
Lithocarpus curtisii	30	Shorea pauciflora	11
Barringtonia macrostachya	30	Shorea multiflora	11
Mangifera lagenifera	28	Diospyros nutans	11
Lithocarpus elegans	28	Macaranga hypoleuca	11
Eugenia grandis	28	Garcinia scortechinii	11
Archidendron bubalinum	26	Shorea leprosula	10
Aglaia grandis	24	Antidesma cuspidatum	10
Macaranga tanarius	23	Baccaurea sumatrana	10
Macaranga triloba	21	Mallotus tiliifolius	10
Aidia densiflora	21	Mesua lepidota	10
Clerodendrum laevifolium	21	Aglaia exstipulata	10
Diospyros schortechinii	20	Knema laurina	10
Nauclea officinalis	20	Neolamarckia cadamba	10
Dipterocarpus costulatus	19	Grewia blattifolia	10
Aporusa confusa	19	Rinorea anguifera	10
Litsea grandis	19	Actinodaphne macrophylla	9
Xerospermum noronhianum	19	Litsea maingayi	9
Callicarpa maingayi	19	Xanthophyllum affine	9
Polyalthia hypoleuca	18	Carallia brachiata	9
Croton argyratus	18	Pavetta wallichiana	9
Sapium baccatum	18	Porterandia anisophyllea	9
Ficus fulva	18	Dillenia reticulata	8
Orchanostachys amentacea	18	Triomma malaccensis	8
Saraca declinata	17	Pentace strychnoidea	8
Memecylon megacarpum	17	Shorea ovalis	7
Nephelium laurinum	17	Croton laevifolius	7
Sterculia cuspidata	17	Litsea lancifolia	7
Canarium littorale	16	Ardisia hullettii	7
Myristica maingayi	16	Xanthophyllum eurhynchum	7
Diospyros sumatrana	15	Xanthophyllum obscurum	7
Epiprinus malayanus	15	Alstonia angustiloba	6
Macaranga conifera	15	Canarium caudatum	6
Cinnamomum iners	15	Sapium discolor	6
Intsia palembanica	15	Cratoxylum maingayi	6
Callerya atropurpurea	15	Sindora coriacea	6
Gironniera nervosa	15	Sandoricum koetjape	6
Endospermum diadenum	14	Knema hookeriana	6
Gonystylus maingayi	6	Dipterocarpus crinitus	3
Rinorea horneri	6	Neobalananocarpus heimii	3
Alangium ebenaceum	5	Antidesma coriaceum	3
Alangium ridleyi	5	Trema angustifolia	3
Hopea nervosa	5	Artocarpus elasticus	3
Elaeocarpus nitidus	5	Ardisia colorata	3
Aporusa nigricans	5	Strombosia javanica	3
Barringtonia pendula	5	Gonystylus affinis	3
Saraca declinata	5	Grewia laevigata	3

Table 2. (*continued*)

Species	No. Stems	Species	No. Stems
Memecylon minutiflorum	5	Polyalthia clavigera	2
Pternandra echinata	5	Shorea macroptera	2
Palaqium obovatum	5	Vatica maingayi	2
Pterospermum diversifolium	5	Galearia maingayi	2
Bouea oppositifolia	4	Adenanthera pavonina	2
Polyalthia lateriflora	4	Archidendron ellipticum	2
Lophopetalum floribundum	4	Dialium platysepalum	2
Elaeocarpus palembanicus	4	Castanopsis fulva	2
Glochidion rubrum	4	Palaquium gutta	2
Flacourtia rukam	4	Pentace triptera	2
Adenanthera malayana	4	Santiria laevigata	1
Pternandra coerulescens	4	Terminalia citrina	1
Xanthophyllum griffithii	4	Hopea dryobalanoides	1
Anisophyllea corneri	4	Shorea guiso	1
Scaphium macropodum	4	Elateriospermum tapos	1
Rinorea sclerocarpa	4	Albizia splendens	1
Campnosperma auriculatum	3	Artocarpus anisophyllus	1
Kokoona reflexa	3	Styrax benzoin	1
		Total	1951

Table 3. Stand density of 10 largest families

Family	Stand density (trees ha^{-1})
Euphorbiaceae	365
Moraceae	201
Dipterocarpaceae	172
Leguminosae	121
Annonaceae	110
Meliaceae	93
Sapindaceae	80
Verbenaceae	79
Lauraceae	72
Rubiaceae	71

Table 4. Stand density by diameter classes

Diameter class (cm)	Trees ha^{-1}
1.0 – 4.9	960
5.0 – 14.9	804
15.0 – 29.9	139
30.0 – 44.9	35
>45.0	12

It therefore appears that through disturbance the study area has been reduced to about half the tree density and species diversity in comparison with the Pasoh 50 ha plot. Examples of species diversity in other forest areas are: Sungai Menyala Forest Reserve, Negeri Sembilan, had 150 species ha^{-1} (Wyatt-Smith 1949), which is about 25% lower in density than the Pasoh 50 ha plot. A lowland forest in Andulau, Brunei had about 140 species ha^{-1} (Ashton 1964) and about 180 species ha^{-1} were recorded in a lowland forest in East Kalimantan (Kartawinata *et al.* 1981). In an alluvial forest and hill dipterocarp forest in Sarawak 225 and 210 species ha^{-1}, respectively, were enumerated (Proctor *et al.* 1983).

The total number of trees ha^{-1} in the study area was 1951 (Table 2). In terms of stand density, the family Euphorbiaceae has the highest number of stem ha^{-1} followed by Moraceae and Dipterocarpaceae. Stand density of trees by diameter class is given in Table 4. Nearly 50% of trees are in dbh class under 5 cm, 40% are 5.0–14.9cm, 7% are 15.0–29.9, 2% are 30.0–44.9 cm and only 1% exceed 45 cm.

Table 5. Above ground biomass of trees 1 cm dbh and above by family

Family	Biomass (t ha^{-1})	Family	Biomass (t ha^{-1})
Moraceae	28.87	Ebenaceae	0.82
Euphorbiaceae	25.38	Hypericaceae	0.82
Dipterocarpaceae	17.57	Sterculiaceae	0.65
Fagaceae	14.06	Thymelaeaceae	0.62
Annonaceae	12.78	Dilleniaceae	0.41
Sapindaceae	10.68	Tiliaceae	0.35
Leguminosae	9.50	Rhizophoraceae	0.22
Rubiaceae	5.95	Styracaceae	0.22
Olacaceae	5.63	Polygalaceae	0.10
Meliaceae	5.33	Apocynaceae	0.07
Anacardiaceae	4.60	Sapotaceae	0.05
Lauraceae	3.56	Celastraceae	0.04
Myrtaceae	3.39	Guttiferae	0.04
Verbenaceae	2.20	Violaceae	0.03
Burseraceae	1.81	Ulmaceae	0.02
Myristicaceae	1.59	Alangiaceae	0.02
Lecythidaceae	1.30	Combretaceae	0.01
Elaeocarpaceae	1.06	Flacourtiaceae	0.01
Melastomataceae	1.05	Myrsinaceae	0.01
		Total	160.08

The presence of many pioneer species, such as *Macaranga* spp. and *Mallotus* spp. from the family Euphorbiaceae, shows that this forest was disturbed in the past and is still at an early stage in succession. The large number of small diameter trees in this stand is also an indication of the early stage of succession. The presence in high density of small-sized primary species, especially dipterocarps, such as *Dipterocarpus cornutus*, shows that the forest has recovered quite well from the 1984 harvesting.

ABOVE GROUND BIOMASS

A summary of the above ground biomass (trees 1 cm dbh and above) by family is shown in Table 5 (Estimated total above ground biomass was 160.8 t ha^{-1}. Moraceae had the highest biomass (28.9 t ha^{-1}) followed by Euphorbiaceae (25.4 t ha^{-1}) and Dipterocarpaceae (17.6 t ha^{-1}). Table 6 shows biomass values by dbh class. Although trees in dbh class (>45 cm) constituted about 1% of the stand density, they contributed about 29% of total above ground biomass, the largest proportion among the dbh classes (Table 6). The biomass obtained from this study is compared with other tropical forest areas in (Table 7).

Table 6. Above ground biomass by diameter class

Diameter class (cm)	Above ground biomass(t ha^{-1})	%
1.0 - 4.9 cm	1.4	0.9
5.0 - 14.9 cm	26.3	16.3
15.0 - 29.9 cm	41.7	26.0
30.0 - 44.9 cm	44.4	27.6
> 45.0 cm	47.0	29.2
Total	160.8	100

Biomass information can be used to quantify nutrients in the ecosystem, provide estimates of carbon content in a forest, quantify forest growth increments, yield or productivity and assess changes in the forest structure. Since biomass is the organic matter fixed by trees, it is thus the source of all other productivity of the forest (Roland and Lim 1999).

CONCLUSIONS

Compartment 121 of Pasoh Forest Reserve is recovering after disturbances in the past, mainly due to logging activities. This is clearly reflected by the species composition of trees, density of trees in different diameter classes which gave a nearly reverse-J curve and the value of the biomass.

Table 7. Comparisons of total biomass (t ha^{-1}) in different study sites (trees > 10 cm dbh)

Site	Total biomass (t ha^{-1})	Source
Mixed dipterocarp-dense stocking, flat to undulating terrain, Sarawak	325-385	FAO (1973)
Lowland forest, Pasoh, Peninsular Malaysia	475	Kato *et al.* (1978)
Lowland dipterocarp forest, Philippines	262	Kawahara *et al.* (1981)
Secondary forest/Sabal Forest	53	Kamaruzaman *et al.* (1982)
Secondary forest, Sibu, Sarawak	6.2	Lim and Basri (1985)
Superior to moderate hill, Peninsular Malaysia	245-310	Forestry Department (1987)
Ayer Hitam Forest Reserve, Peninsular Malaysia	84-232	Roland and Lim (1999)
Pasoh Forest Reserve (Compt. 121, Peninsular Malaysia	139	Present study

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9

Effects of Different Land Use Patterns on the Stream Water Quality in Pasoh, Negeri Sembilan, Malaysia

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Abstract

The study focused on the effect of land use activities on stream water quality in Pasoh, Negeri Sembilan, Malaysia. The stream originates in Pasoh Forest Reserve, Negeri Sembilan and then flows through four different types of land use: undisturbed forest, swamp, degraded logged-over forest and agriculture. Water quality parameters chosen for the study include pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), ammoniacal-nitrogen (NH_3-N), temperature, electrical conductivity (Ec) and turbidity. Stream flow rate was also measured. Computation of water quality status was based on Department of Environment's (DOE)-Water Quality Index (DOE-WQI) and Harkin's Index (HI). Relatively higher values of water quality parameters (DO, BOD, COD, NH_3-N, SS and turbidity) and lower value of pH were recorded in the agricultural area. Water quality status started to degrade after the stream passed through the swampy area (DOE-WQI = 88.9, HI = 26.0) and its water quality status was slightly degraded (DOE-WQI = 91.7, HI = 24.0) in the logged-over forest. Overall analysis showed that the water quality status within the agricultural area (DOE-WQI = 92.04, HI = 34.0) was significantly degraded. Stream flow rate plays a significant role in maintaining the water quality status through aeration effects. All sections of the stream fall under Class II (high quality) in terms of overall water quality status classification.

INTRODUCTION

Water is essential to sustain life, development and the environment. However, Malaysia is presently having water shortages in many areas, even though rainfall in the country averages about 3000 mm. The main problem is not the quantity but the quality of the water. Deteriorating water quality due to rapid development is threatening available water resources for various uses. Water quality can vary along a river depending on land use such as undisturbed forest, rehabilitated logged-over forest, agricultural areas and settlement. River pollution occurs not only from discharges of man-made pollutants, but also from unpredictable sources known as non-point sources including run-off from agricultural, forested and mining areas. A river may be polluted upstream by a non-point source when one of its tributaries passes through a particular land use area. It is necessary to monitor

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and manage the quality of various stretches of the river to check the changes in the characteristics of the water to sustain the various uses of river water.

Many factors, natural and artificial, can affect water quality. Natural factors include weather, watershed characteristics (topography, vegetation, fauna, etc.), geology, microbiological condition and saltwater intrusion. Rapid development of land use and other human activities (agriculture, wastewater discharges, mining, urbanisation and recreation) exert great effects on water quality. Agricultural activities can contribute to water quality deterioration through the release of sediments, pesticides, animal manures, fertilisers, and other sources of inorganic and organic matter. Therefore, agriculture is recognised as a significant non-point source of water pollution. Agriculture and other developments in a river stream can increase the salt content of river water. Forest is an important natural resource which acts as water catchment area but logging, agriculture, road building and other development projects have adverse impacts on the forest ecosystem, including the water regime. The water quality conditions over a large basin area such as the Terengganu River basin are a function of many complex natural and artificial causes. River segments may also receive significant pollution loadings from sources other than municipal and industrial discharges such as runoff from crop lands, urban storm runoff or from roads and other construction sites (Azizi *et al.* 1997, Mohd Kamil *et al.* 1997). Improper management of land use activities may become a major factor causing stream pollution.

The quality of water flowing from an undisturbed, forested watershed is generally regarded as high and meets standards for potable uses (Feller and Kimmins 1979). Its organic and inorganic constituents reflect the mineralogy of the basin, the character of the precipitation and the nature of the vegetal cover (Hewlett 1982). Vegetation modifies sediment load of streams by protecting land and channel surfaces against the scour of flowing water, and by reducing the magnitude of stream flows. Vegetal cover can protect the soil surface from water erosion but if cover is poor, 5-14 t $ha^{-1}year^{-1}$of soil is delivered to streams in regions of erosive soil and well-defined drainage systems (Johnson and Moldenhauer 1970). So we need to know the effects of vegetal cover and water on the soil. Vegetative cover consists of the canopy of living and dead stems and leaves that are clear of the soil, the accumulation of dead and decaying plant remains on or in the soil surface, and the living and dead roots and subsurface stems that permeate the soil.

Organic colloids are a significant constituent of natural sediments (Holt *et al.* 1970). Organic matter decomposition may form many organic acids in water. Organic acids, that change the pH of natural waters, occur within almost all natural environments and in solids, colloidal, dissolved, and gaseous (Hedges 1990). Most organic acids are weak acids and readily biodegradable so they occur in aquatic systems in fairly low steady-state concentrations (Frimmel 1990). Moreover, small accumulations of leaves and other plant debris produce low dissolved oxygen concentrations in the sediments where the tolerant animals can mostly successfully survive and reproduce (Connelk 1981). When sediment is transported to surface water, it contains N in the forms of organic-, NH_4-N, NO_2-N and NO_3-N (Holt *et al.* 1970). Before being deposited the sediment will probably lose soluble organic N and NO_3-N, whereas the insoluble organic N and NH_4-N will essentially remain with the sediment. The organic matter and finer particles of soil are more vulnerable to erosion than the coarser soil fractions (Barrows and Kilmer 1963). Significant quantities of N and P may be removed in the organic phase (Martin *et al.* 1970).

Water quality index (WQI) is a single numerical expression which reflects the combined influence of various significant water quality parameters. This index is getting attention in many countries as it can be used to indicate water quality status and to classify the rivers by their water quality status. From 1987 to 1993, the Department of Environment used WQI to reflect river water quality status of 116 rivers in Malaysia (Rohani and Tan 1997).

This study focuses on the effects of land use activities (undisturbed-forested area, swamp, degraded logged-over forest and agriculture) on stream water quality.

SITE DESCRIPTION

The study site is in compartment 121, Pasoh Forest Reserve, Jempol, Negeri Sembilan at latitude 3° 0.74'N and longitude 102° 21.11'E in Peninsular Malaysia. The site was carefully selected to include a stream flowing through various land uses. The study area is situated within a valley and the stream flows from the hilly area through the valley to the flat area. The stream flows through undisturbed-forest (S1), swamp (S2), degraded logged-over forest (S3), and an agricultural area (oil palm and cocoa) (S4). Each land use activity had a sampling station where the water quality could be analysed. Locations of the four stations are shown in Figure 1. Tropical rain forest is the main vegetation on the undisturbed-forested area and bushes and ferns dominate the swamp. The logged-over forest was clear-cut and left idle in 1984 so the vegetation is dominated by pioneer species. A rehabilitation project was carried out in the logged-over forest in 1995. Oil palm and cocoa are planted in the agricultural area. The approximate rainfall in the study area was obtained from the nearest climatological station, FELDA Pasoh Dua (latitude 2°56'N and longitude 102°18'E). Annual total rainfall for 1995, 1996 and 1997 was 2341 mm, 1842 mm and 1450 mm respectively. In 1998 there was 252 mm from January to March. The topography is undulating with elevation 500-600 m a.s.l.

METHODOLOGY

Parameters Measured

Parameters measured include pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal-nitrogen (NH_3-N), temperature (°C), conductivity (EC) and turbidity. Table 1 shows the analytical methods adopted throughout the study. pH, DO, BOD_5, COD, TSS and NH_3-N are six key parameters for the computation of water quality index. Besides water quality, flow rates of the stretches were measured during the water sampling using a current meter.

Sampling Design, Field Work and Sample Preservation

Field work included collection of stream water and *in-situ* measurement. Measurements of pH, water temperature, DO, flow rate and conductivity were carried out *in-situ*. All the relevant water samples were preserved according to APHA (1995). Sampling took place throughout 1998 and covered both wet and dry seasons. The total sampling frequency was 12 times for each sampling station.

Table 1. Methods of analysis

No.	Parameters	Method of analysis
1	pH	Orion digital pH meter
2	Dissolved oxygen (DO)	Dissolved oxygen meter (YSI 58)
3	Temperature	Thermistor probe (YSI 58)
4	Electrical conductivity (EC)	HACH conductivity meter
5	Biochemical oxygen demand (BOD_5)	Modified Winkler method
6	Chemical oxygen demand (COD)	Reflux method
7	Suspended solids (TSS)	Gravimetric method
8	Ammoniacal-nitrogen (NH_3-N)	Salicylate method
9	Turbidity	Absorptometric method
10	Flow rate	Velocity area method

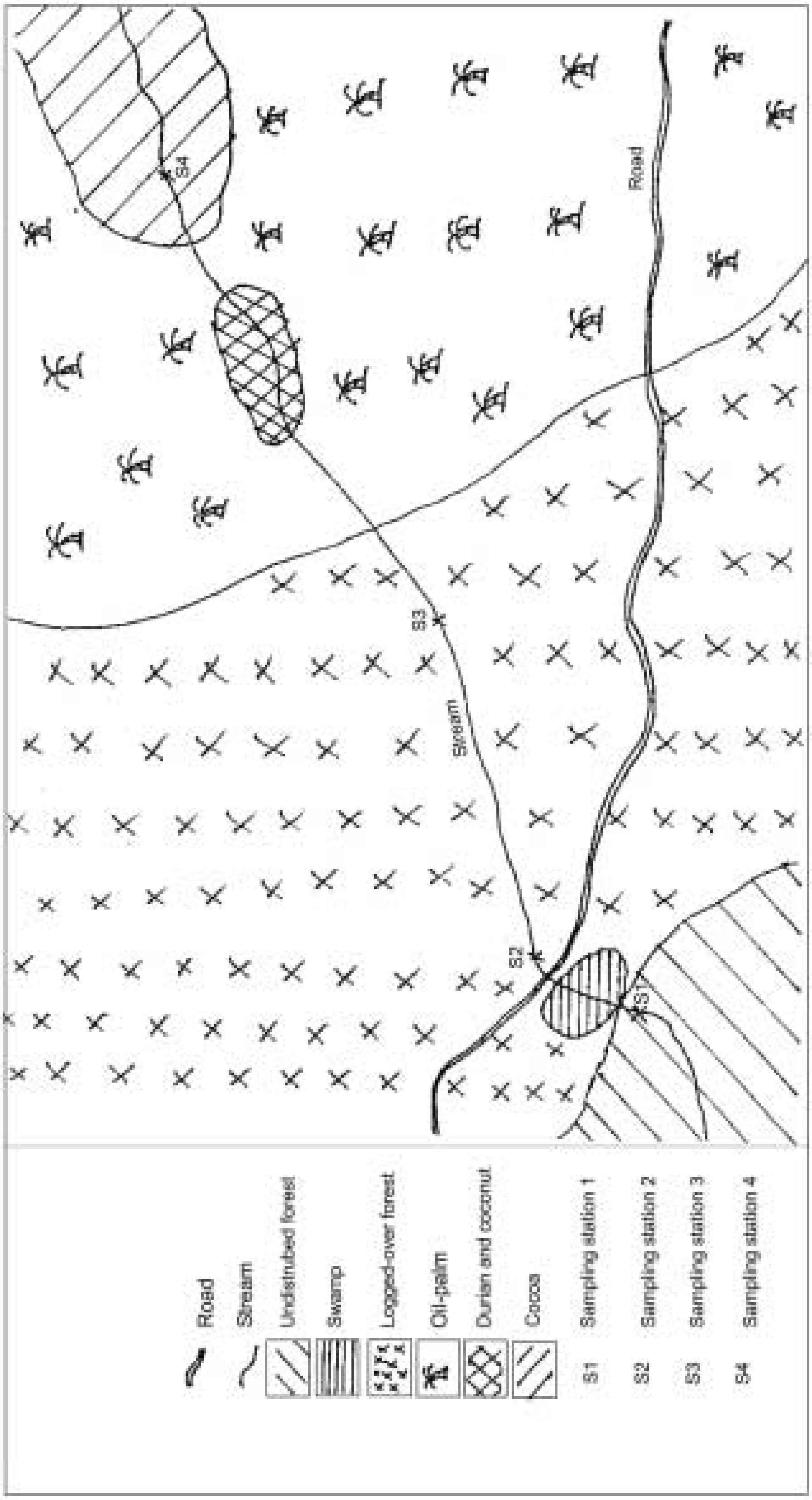

Figure 1. Location of stream and sampling locations

Data Analysis and Water Quality Index

Data from the sampling locations were statistically analysed using Analysis of Variance (ANOVA) to evaluate the changes in water quality status of the stretches of the stream over the study period. Two methods of water quality index calculation were used namely Department of Environment (DOE) opinion-poll WQI (DOE-WQI) and Harkin's Water Quality Index. It is difficult to assess the water quality status based on so many parametric values since the water quality parameters behave very differently among one another. In light of this observation, there is a need to apply a single numerical expression, the water quality index, which reflects the composite influence of the various significant water quality parameters (DOE 1994).

Harkin's Index. This objective index follows a statistical approach based on the rank order of observations compared to a set of control values. Usually a set of water quality standards or recommended limits were used as control values (Harkin 1974). In this study, the parameters are the same as those for the DOE-WQI. The parameters are DO, BOD, COD, AN, TSS and pH. Table 2 shows the classification of water quality according to Harkin's Index.

Table 2. Classification of water quality according to Harkin's Index

Harkin's Index	Class
0-28.5	I
<38.0	II
<42.5	III
<45.5	IV
Other values	V

Harkin's Water Quality Index is an application of Kendall's nonparametric multivariate ranking procedure and there are four steps to compute it:

1. For each parameter, set a control value and standard values for each class of water quality.
2. Rank each column of water quality parameters, including the standard values. Tied ranks are split in the usual manner. In subsequent calculations, the rank values are used in place of the actual value of the parameter. The rank names of the six parameters used in this study are RDO, RBOD, RCOD, RAN, RSS and RpH.
3. Compute the rank variance V(i) for each rank values of the ith parameter using the equation:

$$\text{Variance, } V_{(i)} = [\ 1/12n\ ] \times [\ (n^3-n) - \sum_{i=1}^{k} (t_j^{\ 3} - t_j)\ ]$$

Where
n = the number of observations plus the number of control points, and
k = the number of ties encountered.
t_j = frequency of the jth ties.
These variances are used to standardise the indices computed. If k=0 (no ties occur), the corresponding summation is to be regarded as a vacuous.

4. For each member or observation vector, compute the standardised distance:

$$HI(n) = \sum_{i=1}^{p} [R_j(i) - R_c(i)]^2/V(i)$$

Where
R_c(I) = rank of the control value for ith parameter;
R_j(I) = rank of the jth observation for the ith parameter;
p = number of parameters (= 6 in this study).

DOE-WQI: The monthly mean values of the six key water quality parameters, namely DO, BOD_5, COD, pH, NH_3-N, and TSS for each stations were chosen for the computation of the WQI and Table 3 shows the index categorisation. Firstly, the mean values of the six water quality parameters were converted to the subindices using the best-fit equations of the rating curves (Norhayati 1981) and then aggregated to compute the WQI according to the following equation:

WQI= 0.22 X SIDO + 0.19 X SIBOD +O.16 X SICOD+0.15 X SIAN + 0.16 X SISS + 0.12 X SIPH

Where SI is the subindex of each parameter.

Table 3. Classification of water quality according to DOE-WQI

DOE-WQI	Class
>96.02	I
>75.37	II
>51.68	III
>29.61	IV
0-29.61	V

RESULTS AND DISCUSSION

The data collected in this study are presented in Table 4 and it comprises average, minimum, maximum and standard deviation (SD) values.

Water pH : Variation in mean pH among sampling stations ranged from 6.31 to 6.71 (Table 4). Water in the undisturbed forest area (S1), had a pH of 6.71 (near neutral) and was statistically significantly higher than the other stations (S2, S3 and S4) which were similar to each other. In natural water, organic acids could be formed by the decomposition of organic matter and this is the main factor that affecting the pH value. Since organic colloids are a significant constituent of natural sediment, the amount of sediment load in natural water is an undoubted factor to explain the different pH values among the sampling stations. It was found that the amount of bed and suspended sediment of S2, S3 and S4 were much higher than S1 thus this may be the main explanation of the lower pH values of S4. Moreover, the lowest pH (6.31) in S4 may be due it having the highest amount of the bed and suspended sediment among the sampling stations.

Dissolved Oxygen: DO values decreased during the dry season. As a result, the mean DO value of S4 (6.94 mg litre^{-1}) is the highest among the stations and it is followed by S1 (6.84 mg litre^{-1}), S3 (6.38 mg litre^{-1}) and S2 (5.98 mg litre^{-1}) (Table 4). The velocity of flowing water at S4 was the highest among the stations and produced more turbulence to increase dissolved oxygen in the water. Although the water at S1 did not flow rapidly, its dissolved oxygen was quite high due to its low organic sediment and the oxygen produced by photosynthesis of green moss on the bed of the stream. The low flow during the dry season may also affect the dissolved oxygen in water. The stream was reduced to many stagnant pools at S1, S2 and S3 during the low flow period. It was observed that leaves and other plant debris in the sediments and their decomposition might consume oxygen in the pools lowering the value of DO. The statistical analysis showed that that the mean DO value of S2 is significantly lower than the other stations (Table 5). As there were many euthrophic pools formed near S2, decomposition of plant debris may have been responsible for the lowest mean DO value.

Biochemical Oxygen Demand: Values of BOD_5 for all the sampling stations were below 2.0 mg litre^{-1} except S4 (2.2 mg litre^{-1}) during the eleventh sampling (Table 4). The low BOD_5 values reflect the small amount of biodegradable organic matter in the stream stretches under study. S1 had the lowest mean value of 0.55 mg litre^{-1}. There are no discharges of sewerage, rubbish and human wastes to the stream in the undisturbed forest (S1) so the very small amount of suspended organic sediment from leaves and other plant debris could be the major reason for the lowest value of BOD_5. S1 and S3 (0.73 mg litre^{-1}) had significantly lower ($p=0.0001$) mean values than S2 (0.96 mg litre^{-1}) and S4 (1.03 mg litre^{-1}). It was observed that there was more suspended sediment at S2 and S4 compared to S1 and S3. During the dry season, sediment at S2 was more than S3 because the decomposition of accumulated leaves and other plant debris have produced more organic sediment. Suspended solids at S4 were the highest among all stations. Since most of the suspended solids are organic matter, the BOD_5 value of S2 and S4 were greater than for S3.

Chemical Oxygen Demand: S1 has the lowest mean value of COD (5.83 mg litre^{-1}) (Table 4). COD values increase downstream reaching a peak at S4 (18.00 mg litre^{-1}). From the field observation, the COD values of all the sampling stations seem to increase dramatically during the dry season. The low flow during the dry season can reduce the dilution of chemicals in the water thus

Table 4. Water quality at each sampling station (pH)

Station	Average	Min	Max	SD
Station 1	6.71	6.00	7.16	0.39
Station 2	6.38	5.85	6.74	0.25
Station 3	6.32	5.75	6.88	0.37
Station 4	6.31	5.76	6.69	0.33
DO(mg litre^{-1})				
Station 1	6.84	4.40	8.80	1.13
Station 2	5.98	3.10	7.60	1.35
Station 3	6.38	3.40	8.00	1.25
Station 4	6.94	5.60	8.00	0.69
BOD_5(mg litre^{-1})				
Station 1	0.55	0.07	1.87	0.51
Station 2	0.96	0.17	1.94	0.53
Station 3	0.73	0.17	1.11	0.30
Station 4	1.03	0.20	2.22	0.51
COD(mg litre^{-1})				
Station 1	5.83	1.00	11.00	3.38
Station 2	10.50	1.00	20.00	5.84
Station 3	13.80	4.00	26.00	6.89
Station 4	18.00	9.00	39.00	10.30
NH_3-N(mg litre^{-1})				
Station 1	0.01	0.00	0.03	0.01
Station 2	0.17	0.01	0.55	0.21
Station 3	0.02	0.01	0.06	0.01
Station 4	0.03	0.00	0.05	0.02
TSS(mg litre^{-1})				
Station 1	1.42	0.00	7.00	1.93
Station 2	4.08	1.00	13.00	3.15
Station 3	2.50	1.00	5.00	1.08
Station 4	6.42	3.00	22.00	5.37
EC(μmhos cm^{-1})				
Station 1	0.07	0.06	0.14	0.02
Station 2	0.08	0.05	0.12	0.02
Station 3	0.06	0.06	0.08	0.01
Station 4	0.06	0.06	0.07	0.00

Table 4. *(Continued)*

Turbidity (FTU)				
Station 1	7.92	5.00	19.00	3.73
Station 2	24.58	10.00	80.00	20.34
Station 3	21.80	13.00	39.00	9.37
Station 4	29.08	14.00	61.00	15.69
Temperature (°C)				
Station 1	25.16	22.50	26.20	0.96
Station 2	25.50	23.60	26.60	0.93
Station 3	25.80	25.00	26.60	0.62
Station 4	27.33	25.00	28.90	1.09
Flow rate (cm^3s^{-1})				
Station 1	4684	205	16160	5179
Station 2	4569	160	13268	4486
Station 3	11224	190	31997	11389
Station 4	9432	1333	25716	9537

Table 5. Summary of Duncan's Multiple Range Test (DMR)

Parameter	Duncan grouping			
	Rank 1	Rank 2	Rank 3	Rank 4
pH	S1	S2	S3	S4
DO	S1	S4	S3	S2
BOD_5	S1	S3	S2	S4
COD	S1	S2	S3	S4
NH_3-N	S1	S3	S4	S2
TSS	S1	S3	S2	S4
EC	S4	S3	S1	S2
Turbidity	S1	S3	S2	S4
Temperature	S1	S2	S3	S4

Each line represents an individual group the values within which are not significantly different. Rank 1, Rank 2, Rank 3 and Rank 4 represent the status of water quality in decreasing order.

this can be used to explain the increase of COD values for the stations. S1 was significantly lower ($p=0.0001$) than S3, S4 because the water is still clean and not polluted within the undisturbed forest. There was no difference between S4 (18.00 mg litre^{-1}) and S3 (13.80 mg litre^{-1}) and S3 did not differ significantly from S2 (10.50 mg litre^{-1}) (Table 5). It was observed that the sediments became higher and the colour of the water turned yellowish downstream compared to upstream. This may explain the increase of COD values along the stream.

Ammoniacal-Nitrogen: Concentrations of ammoniacal nitrogen were not greater than 0.06 mg litre^{-1} nitrogen during the sampling period for all the stations except S2 (Table 4). The mean value of S2 is the highest due to the abnormal higher concentrations of ammoniacal-nitrogen during the dry season. Even though there were a few higher values during the dry season, the mean value of S2 was only 0.17 mg litre^{-1} because its highest value is 0.55 mg litre^{-1}. There were significant differences between the stations with S2 significantly higher (Table 5). In the dry season, the flow rate was very low and the stream flowed so slowly that many small ponds were formed along the stream especially at S2. Many fish were trapped in the small ponds and the metabolic wastes from the fish increased the content of ammoniacal nitrogen in the water. In addition, the decomposition of leaves and other plant debris by microorganisms is believed to have contributed more nitrogen compounds to the water.

Total Suspended Solid: Mean values of TSS were generally low (Table 4). S4, located at agricultural area, had the highest mean value (6.42 mg litre^{-1}) and S1, in the undisturbed-forested area, the lowest (1.42 mg litre^{-1}) because the soil surface there is protected by the vegetal cover and the water is very clear. There were significant differences between the stations ($p=0.0036$). Moreover, DMR test classified the stations into two groups. S1, S2 and S3 were not significantly different from each other (Table 5) and S2 and S4 were not significantly different from each other. As vegetation can protect the soil surface and channel surfaces against the scour of water of flowing water, it can explain the lower TSS values at S1, S2 and S3 that have more vegetation than S4, in a cocoa plantation area. The cocoa trees were planted at a distance of about 3 m from each other, there was no other vegetal cover within the area and the stream bank had no vegetation to protect it and the channel surface. As a result, the TSS value of S4 is the highest because more soil particles could be easily picked up by the run-off water and eventually carried into the water. Moreover, all the sediments produced at upper stream were accumulated on the bed of S4 and sometimes the turbulence may have caused some small particles to be suspended in the water again.

Conductivity: The variation of the value of conductivity is small (Table 4). There were significant differences between the stations ($p= 0.00308$). S3 and S4 are significantly different from S2 but not from S1. S1 and S2 are not significantly different from each other (Table 5). The mean EC values range from 0.06 to 0.08 mS cm^{-1}. Values at S1 and S2 increased during the dry season. As stated previously, many stagnant pools formed near S2 in the dry season and these pools were joined when the flow rate increased. Ions accumulated daily in the pools from fish waste and decaying leaves until their concentration was many times higher than in the normal period. Therefore, the EC at S1 and S2 can be at least twice that of samples taken in other periods. However, the values of S3 and S4 were quite stable during the whole sampling period, possibly due to the higher flow rates which provided sufficient assimilative capacity to reduce the EC to normal values.

Turbidity: There was significant variation of turbidity ($p= 0.0004$) among the sampling stations (Table 4). Mean values ranged from 7.92 to 29.08 FTU. S1 had the lowest value of turbidity (Table 5) because the soil surface and channel surface is protected by the vegetation in the forest and it contributes only a small amount of suspended matter in the stream.

Temperature: S4 had the highest mean temperature (Table 4). Temperature increased downstream peaking at S4 (27.3°C). S4 is located in a cocoa plantation area and was exposed to sunlight during sampling. S1 (25.2°C), S2 (25.5°C) and S3 (25.8°C) reflect the decrease of vegetation along the stream and greater exposure of the downstream stations to sunlight.

Summary of Duncan's Multiple Range Test

This test showed the trend of each parameter along the stream (Table 5). The stations are ranked for each parameter based on their water quality status in decreasing order. S1 is ranked 1 for all parameters except conductivity which shows the undisturbed forest provided protection and maintained good quality of water resource. In contrast, the agricultural area, S4 is ranked 4 for six parameters including BOD_5, pH, COD, TSS, turbidity and temperature. S2 and S3 are always in Rank 2 and Rank 3 showing that the water quality of the stream is decreasing as it flows from the forested area to the logged-over forest and into the agricultural area. Nevertheless, the value of dissolved oxygen in the agricultural area (S4) is the second highest due to turbulence increasing water oxygen before S4. Water quality, especially dissolved oxygen, conductivity and ammoniacal-nitrogen, in the swamp (S2) is affected negatively by flow rate rather than by the type of land use.

Water Quality Status

Table 6 shows the DOE-WQI and Harkin's Index computed for the sampling stations associated with the classification of water quality status. All the stations were in class II which indicates the water quality status of the river water at the project site is high. Based on DOE-WQI and Harkin's Index, the most significant degraded water quality was in the agricultural area and this may due to fertiliser application and decomposition of agricultural wastes.

CONCLUSION

Relatively, higher values of DO, BOD_5, COD, NH_3-N, TSS and turbidity, and a lower pH, were observed in the agricultural area. The changes of water quality parameters began after the stream passed through the swamp area and the logged-over forest, although the water quality within the logged-over forest (between S2 and S3) is affected. Water quality was degraded most in the agricultural area.

The water quality of the small stream varies depending on the rainy season and dry season. Besides land use activities, the flow rate has played a significant role in determining the water quality in the small stream. In spite of that, the degradation effect at downstream may not be observed as clearly as in the forested and logged-over forest areas because the flow rate tends to increase downstream (as in S4).

The overall classification of each water stretch was Class II, indicating good water quality. However, DOE-WQI was able to show that the water quality of undisturbed-forested area was better than the water quality of the logged-over forest and agricultural area. Harkin's index classified the water quality in the agricultural area as class II and other areas as Class I. This leads to the conclusion that the water quality in the stream varies due to different types of land use activities, being best in the undisturbed forest area.

Table 6. River classification based on DOE-WQI

Sampling Station	DOE-WQI	Harkin's Index	Overall class
S1	95.29 (II)	17.0 (I)	II
S2	88.87 (II)	26.0 (I)	II
S3	91.68 (II)	24.0 (I)	II
S4	92.04 (II)	34.0 (II)	II

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10

Soil Conditions under Natural, Logged-over and Secondary Stands of Tropical Seasonal Forest in Thailand

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Abstract

Soil samples from permanent sample plots of natural mixed deciduous, logged-over mixed deciduous and the secondary stands in the tropical seasonal forest were analysed for physical and chemical properties. Bulk density and soil hardness of A-horizon in the natural stand were slightly higher than in logged-over and the secondary stands with average bulk densities 1.2, 1.1 and 1.0 g cm^{-3} and soil hardness 17, 16 and 15 respectively. Secondary stands had slightly higher B-horizon hardness than the natural and the logged-over stands. Total pore value (volumetric %) of the secondary stand was higher than the logged-over and the natural stands with the average of 48, 45 and 42 % respectively. Secondary stand fine pore percentage was also higher than that of the natural and the logged-over stands with the average of 29, 25 and 24 % respectively. Soil permeability was highest in the secondary stand with an average of 122 ml minute^{-1} while in logged-over and natural stands it was are 116 and 45 ml minute^{-1} respectively. Soil organic matter in the secondary, natural and logged-over stands was 7.3, 6.0 and 5.0% respectively. There is much variation in P, K, Ca and Mg content in all stands. The maximum content of P in the natural, logged-over and secondary stands are 35, 57 and 26 ppm. respectively, while the minimum P content was 4, 4 and 2 ppm respectively. Average P contents were in the range 9-12 ppm. The average K content in natural, logged-over and secondary stands was 188, 230 and 555 ppm, average Ca was 963, 938 and 1109 ppm, and average Mg 289, 528 and 413 ppm respectively. It is concluded that there is little difference in most soil properties in these stands, except soil permeability in the natural stand is lower than in the other two stands. This may be the effect of high soil bulk density and the low coarse pore volumetric percentage.

INTRODUCTION

The problem of increased degradation of forests in tropical regions, including Thailand, is of concern. Degradation of forest land is caused by many factors, such as climatic changes and pests and diseases, but human activities are the most important. These activities include improper farming, timber harvesting, shifting cultivation, conversion of forest land to agriculture or other land use. It is essential to solve the problem and to rehabilitate degraded areas. In order to do this, basic information, such as the condition of vegetation cover and soil is needed. The objective of this study was to understand the soil conditions of natural mixed deciduous forest, the previously harvested mixed deciduous forest and secondary forest after shifting cultivation.

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STUDY SITE

The study was carried out in permanent sample plots, each of 4 ha, at Maeklong Watershed Research Station, Thong Pha Phume District, Kanchanaburi Province, western Thailand at latitude 14°30′-14°45′N and longitude 98°45′-99°0′E. The climate is monsoonal, the mean annual temperature is about 27.5°C with the maximum of 39°C in April and the minimum of 14°C in December. Annual precipitation normally exceeds 1650 mm, mean monthly relative humidity is 68%. (Suksawang 1995).

Location of Permanent Sample Plots

Plot 1 was located in natural mixed deciduous forest and the upper part of the plot extended to dry dipterocarp forest. It was also located along the slope of the mountain facing south, the elevation difference between the upper and lower parts of the plot was about 95 m. Plot 2 was in logged-over mixed deciduous forest. This plot covered a small hill with a Y-shape creek, the elevation difference between the highest and lowest points was about 85 m. Plot 3 was in a previous shifting cultivation area on a gentle slope (Yarwudhi *et al.*1995, Takahashi *et al.* 1995).

Vegetation

Yarwudhi *et al.* (1995) reported that there were 103 tree species of girth breast height (GBH) greater than 15 cm in Plot 1 (Table 1). Among these species *Shorea siamensis* had the highest IVI (Important Value Index) of 25.05 followed by *Berrya ammonilla, Dillenia parviflora, Bombax anceps, Xylia xylocarpa* and *Sterculia macrophylla.* The basal area of trees was 17.8 m^2 ha^{-1}. The total number of trees recorded was 719. For Plot 2, there were 101 tree species of GBH greater than 15 cm, *Sterculia macrophylla* had the highest IVI of 45.18 and the next *were Lagerstroemia tomentosa*, *Colona floribunda*, *Dillenia obovata, Ficus hispida* and *Xylia xylocarpa*. The basal area was 17.1 m^2 ha^{-1} and the total number of trees was 789. For Plot 3, there were 25 trees species of GBH greater than 15 cm and *Trema orientalis* which is considered as pioneer species of this area had the highest IVI of 163.61 and then *Xylia xylocarpa, Dipterocarpus turbinatus, Garuga pinnata, Ficus hispida* and *Gmelina arborea*. The basal area in this plot was very low 0.51 m^2 ha^{-1} and the total number of trees was 407.

For understorey vegetation Takahashi *et al.* (1995) reported 3, 4, and 5 vegetation types in Plot 1, Plot 2 and Plot 3 respectively (Table 1). The five vegetation types were bamboo type (*Gigantochloa albociliata, G. hasskaliana and Bambusa tulda*), woody shrub type (*Trema orientalis, Sterculia macrophylla, Bauhinia virinescens and Colona floribunda*), banana type (*Musa acuminata*), *Eupatorium odoratum* type and *Bothrichloa* sp. type. They also found bamboo type vegetation covered 89.7, 35.7, and 0.2% of the area of Plot 1, Plot 2 and Plot 3 respectively.

METHODS

Soil Sample Collection

Undisturbed soil samples were collected at approximately the centre of each grid (20 x 20 m) of 4 ha permanent sample plots using 400 cm^2 cylinder soil cores. 50, 50 and 60 samples were taken from the permanent sample plots of the natural (Plot 1), logged-over (Plot 2) and secondary (Plot 3) stands respectively. Disturbed soil samples about 5 kg was taken at the same place as the undisturbed soil samples. A_0, and A-horizons' thickness and the hardness of A and B-horizons was measured in soil pits.

Determination of Soil Physical Properties

Fresh weight of undisturbed soil samples was recorded before soaking them in water for 24 hours to determine their saturated weight. The saturated soil samples were placed on porous plates for at least 48 hours to let the water drain out. The volume drained out is approximately equal to the volume of coarse pores. Total soil pore volume was determined by saturated weight – oven dry weight, and fine soil pore volume by total soil pore

Table 1. Vegetation of the study area

Category	Natural stand Plot 1	Logged-over stand Plot 2	Secondary stand Plot 3
Number of species	103	101	25
Total number of trees	719	789	407
Species of high important value index (IVI)	*Shorea siamensis* (25.05)	*Sterculia macrophylla* (45.18)	*Trema orientalis* (163.61)
	Berrya ammonilla (16.08)	*Lagerstroemia tomentosa* (19.40)	*Xylia xylocarpa* (17.25)
	Dillenia parviflora (11.66)	*Colona floribunda* (15.17)	*Dipterocarpus turbinatus* (15.45)
	Bombax anceps (11.50)	*Dillenia obovata* (14.23)	*Garuga pinnata* (14.82)
	Xylia xylocarpa (11.03)	*Ficus hispida* (13.61)	*Ficus hispida* (12.84)
	Sterculia macrophylla (8.24)	*Xylia xylocarpa* (11.64)	*Gmelina arborea* (9.63)
Basal area ($m^2 ha^{-1}$)	17.80	17.13	0.51
Understorey vegetation type (%)			
Bamboo type	89.7	35.7	0.2
Woody shrub type	3.0	23.0	20.0
Banana (*Musa acuminata)* type	7.3	38.0	14.8
Eupatorium odoratum type	0.0	3.3	39.5
Arundo donax type	0.0	0.0	17.0
Bothrichloa sp. type	0.0	0.0	8.5

Modified from Yarwudhi *et al.*(1995) and Takahashi *et al.*(1995)

volume – coarse pore volume. Soil permeability was determined using the constant water head method with undisturbed soil samples.

Soil Chemical Properties

Disturbed soil samples were sent to Department of Agriculture, Ministry of Agriculture and Cooperatives for soil chemical analysis.

RESULTS AND DISCUSSION

Soil Physical Properties

Thickness and hardness of A and B-horizons

A_0–horizon thickness in the natural, logged-over and secondary stands of mixed deciduous forest ranged from 0-5 cm (Table 2) with the logged-over stand the thickest and followed by the natural stand. Soil hardness of both A and B-horizons for all plots was similar (Table 2).

Soil moisture content

Plot 3 had an average value of 19.1% (field moisture content) while Plot 1 and Plot 2 were 10.0% and 12.3% respectively. There was much variation in soil moisture contents in Plot 3 which may be the cause of slightly lower soil hardness values in both A and B layers and the high volumetric percentage of fine pores (Table 2) and the high value of soil organic matter (Table 3). The relationship between soil hardness and soil moisture content is shown in Figure 1. There was a weak tendency for soil hardness to decrease when soil moisture increased.

Table 2. Soil physical properties in natural, logged-over and secondary stands of tropical seasonal forest

Soil properties		Natural stand (Plot 1)	Logged-over stand (Plot 2)	Secondary stand (Plot 3)
A_0-horizon thickness(cm)	Range.	0 –5	0-5	0-7
A-horizon thickness(cm)	Range	3-19	3-20	3-16
Hardness (mm)	Max.	27	26	26
	Min.	9	8	5
	Mean	**17**	**16**	**15**
	SD	3.6	3.6	4.2
Moisture content (%)	Max.	23.1	23.0	47.8
	Min.	0	4.1	11.0
	Mean	**10.0**	**12.3**	**19.1**
	SD.	3.9	3.8	6.9
B-horizon hardness (mm)	Max.	36	32	31
	Min.	12	19	6
	Mean	**26**	**26**	**27**
	SD.	3.5	2.8	4.0
Bulk density (g cm^{-3})	Max.	1.4	1.2	1.3
	Min.	0.9	0.9	0.8
	Mean	**1.2**	**1.1**	**1.0**
	SD	0.09	0.09	0.10
Total pores (volumetric %)	Max.	50.8	50.6	70.5
	Min.	18.2	39.6	29.8
	Mean	**41.6**	**45.1**	**47.9**
	SD	5.2	2.3	5.7
Coarse pores	Max.	20.9	42.2	45.0
	Min.	10.1	16.9	0.5
	Mean	**16.3**	**21.6**	**19.2**
	SD.	2.4	3.9	5.3
Fine pores	Max.	40.7	29.9	52.8
	Min.	2.7	0	21.7
	Mean	**25.3**	**23.5**	**28.7**
	SD	5.2	4.2	4.6
Permeability (cc min^{-1})	Max.	128	311	394
	Min.	5	18	132
	Mean	**45**	**116**	**122**
	SD	28.4	54.4	74.7

Soil bulk density

There was little difference in bulk density in the plots (1.2, 1.1 and 1.0 g cm^{-3} respectively). The highest recorded, 1.4 g cm^{-3} was found in Plot 1. Soil with low bulk density was mostly found on the lower slope where litter accumulation is high in all plots.

Volumetric percentage of soil pores

Total soil porosity in Plot 3 varied between 29.8-70.5%. The average total pore volumetric percentage in Plot 3 was higher than Plot 1 and Plot 2 with values of 47.9, 45.1 and 41.6% respectively (Table 2). For the average coarse pore volumetric percentage, Plot 2 was higher than Plot 1 and Plot 3, with the values of 21.6, 16.3 and 19.2 % respectively. On the other hand, the average fine pore volumetric percentage of Plot 3 was the highest with the value of 28.7% while Plot 1 and Plot 2 were 25.3 and 23.5% respectively. The relationship between bulk density and total pore volumetric percentage is shown in Figure 2. Bulk density decreases as total pore volumetric percentage increases.

Soil permeability

Soil permeability in secondary forest (Plot 3) was much higher than the other plots but there was much variation in permeability values in all plots. The maximum in Plot 1, Plot 2 and Plot 3 were 128, 311 and 394 cc minute^{-1} respectively (Table 2) and the minimum of the three plots were 5, 18 and 132 cc minute^{-1} respectively. The average permeability for each plot were 45, 116 and 122 cc minute^{-1} respectively. High permeability in Plot 3 may be the effect of low bulk density and high total pore volumetric percentage.

Soil Chemical Properties

Soil organic matter

Maximum soil organic matter in the natural stand (Plot 1) and secondary stand (Plot 3) was the same (11.7%) while in the logged-over forest (Plot 2) it was 6.7%. The minimum values were 3.5, 3.3 and 4.3 % for Plot 1, Plot 2 and Plot 3 respectively. Plot 3 had the highest average organic matter (7.3%) followed by Plot 1 (6.0%) and Plot 2 (5.0%) (Table 3). The high organic matter in Plot 3 may be the effect of ground cover vegetation and high soil moisture content, even though this area was burned frequently before the study.

Available phosphorus

The logged-over forest (Plot 2) had the maximum available phosphorus (57 ppm) compared to Plot 1 (35 ppm) and Plot 3 (26 ppm). The minimum available phosphorus in Plot 1 and Plot 2 was 4 ppm with Plot 3 only 2 ppm. Average available phosphorus in Plot 2 was the highest (12 ppm) followed by Plot 1 (11 ppm) and Plot 3 (9 ppm) (Table 3). The low value of available phosphorus, as observed in Plot 3, is the outstanding feature of the surface soil in degraded ecosystems (Ohta *et al.* 2000).

Available potassium

Available potassium was high in Plot 3 with a maximum of 625 ppm, minimum 108 ppm and average of 554.6 ppm. Plot 2 followed with a mean of 231 ppm and Plot 3 was lowest with an average of 188 ppm (Table 3).

Available calcium

Available calcium was also high in Plot 3 with a maximum of 3741 ppm, a minimum of 73 ppm and an average of 1109 ppm., but less in Plot 1 with 2464 ppm, 206 ppm, and 963 ppm respectively and Plot 2. (Table 3).

Available magnesium

Available magnesium was highest in Plot 2 with the maximum of 739 ppm, minimum of 224 ppm and average of 528 ppm., and least in Plot 1 (Table 3).

CONCLUSION

From the analysis of soil physical and chemical properties in three different stand conditions i.e. natural, logged-over and secondary, we conclude that there is little difference among almost all soil properties measured. An exception is soil

Table 3. Soil chemical properties in natural, logged-over and secondary stands of tropical seasonal forest

Soil properties		Natural stand (Plot 1)	Logged-over stand (Plot 2)	Secondary stand (Plot 3)
Organic matter (%)	Max	11.7	6.7	11.7
	Min	3.5	3.3	4.3
	Mean	**6.0**	**5.0**	**7.3**
	SD	1.7	0.7	1.7
P (ppm)	Max	35	57	26
	Min	4	4	2
	Mean	**11**	**12**	**9**
	SD	7	8	5
K (ppm)	Max	360	420	625
	Min	75	95	108
	Mean	188	231	555
	SD	59	71	136
Ca (ppm)	Max	2464	1801	3741
	Min	206	387	73
	Mean	**963**	**938**	**1109**
	SD	476	327	814
Mg (ppm)	Max	691	739	601
	Min	51	224	82
	Mean	**289**	**528**	**413**
	SD	140	117	130

Figure 1. Relationship between soil hardness and soil moisture content

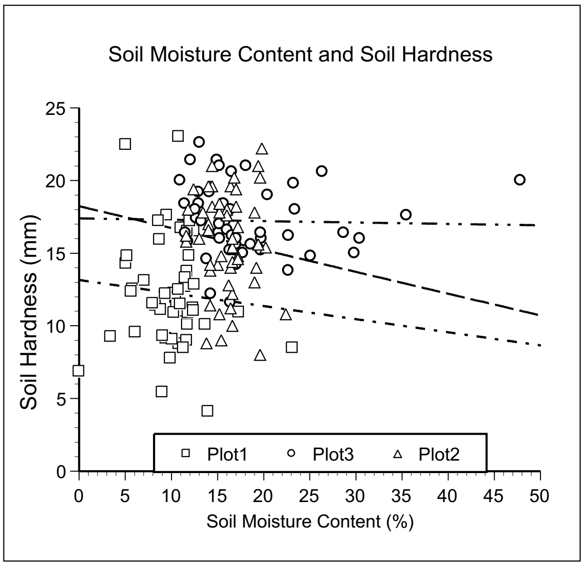
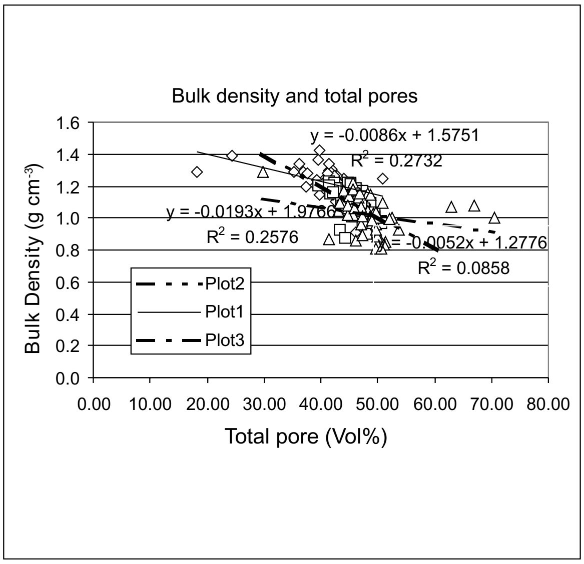


Figure 2. Relationship between soil bulk density and total pore volumetric percentage



permeability of the natural stand, which is low compared to the other two stands and this may be the effect of high soil bulk density and low coarse pore volumetric percentage. The logged-over area has recovered from the harvesting because soil and vegetation conditions are similar to those in the natural stand.

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